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Wong et al.

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(45) **Date of Patent: Jul. 30, 2019**

(54) **MULTI-ANTENNA COMMUNICATION DEVICE**

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(73) Assignee: **Industrial Technology Research Institute**, Hsinchu (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 219 days.

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(22) Filed: **Dec. 28, 2016**

(65) **Prior Publication Data**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
H01Q 1/24 (2006.01)
H01Q 7/00 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01Q 7/00*** (2013.01); ***H01Q 1/243*** (2013.01); ***H01Q 1/48*** (2013.01); ***H01Q 21/28*** (2013.01)

(58) **Field of Classification Search**
CPC H01Q 1/24; H01Q 1/48; H01Q 21/28; H01Q 7/00; H01Q 1/243; H01Q 21/06; H01Q 21/061
See application file for complete search history.

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Primary Examiner — Jessica Han
Assistant Examiner — Awat M Salih
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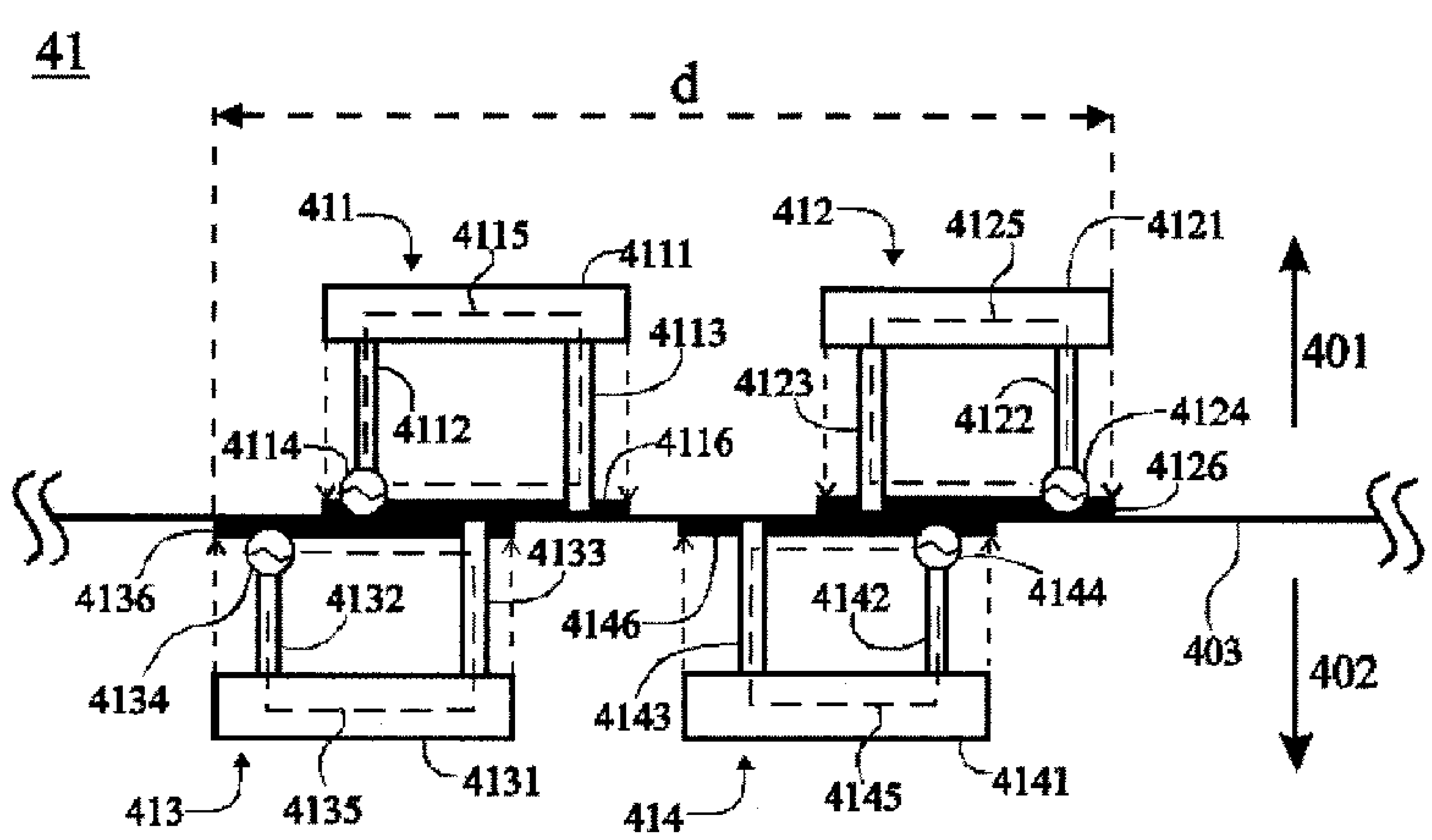
(57) **ABSTRACT**

A multi-antenna communication device is provided, including a grounding conductor plane separating a first side space and a second side space and having a first edge. A four-antenna array including first, second, third and fourth antennas is located at the first edge, and has an overall maximum array length extending along the first edge. The first and second antennas are located in the first side space, and the third and fourth antennas are located in the second side space. Each of the first to fourth antennas includes a feeding conductor line, a grounding conductor line, and a radiating conductor portion electrically connected to a signal source through the feeding conductor line and electrically connected to the first edge through the grounding conductor line, thereby forming a loop path and generating at least one resonant mode. The radiating conductor portion has a corresponding projection line segment at the first edge.

19 Claims, 14 Drawing Sheets



(51) **Int. Cl.**

H01Q 1/48	(2006.01)
H01Q 21/28	(2006.01)

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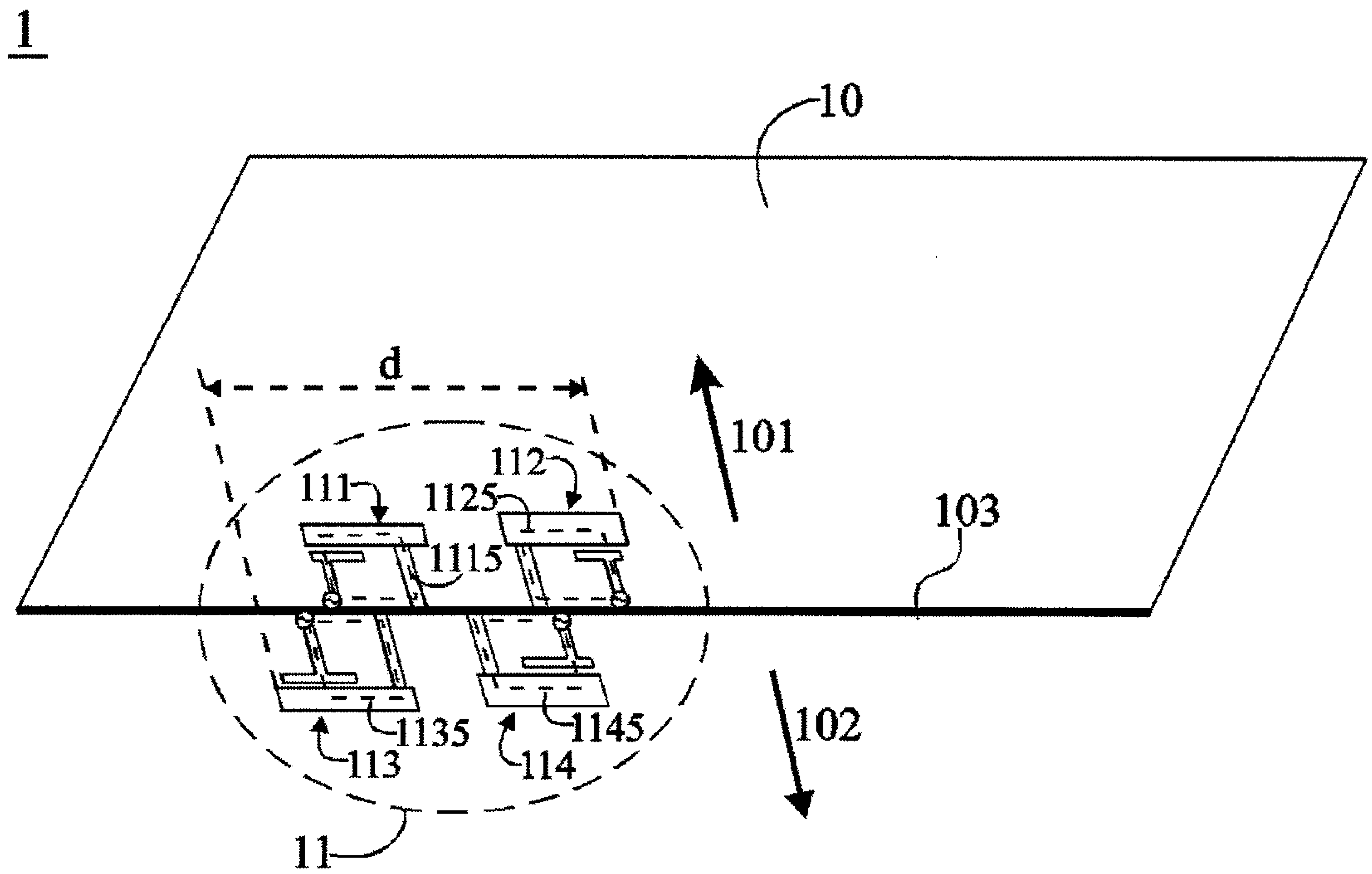
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10
d
101
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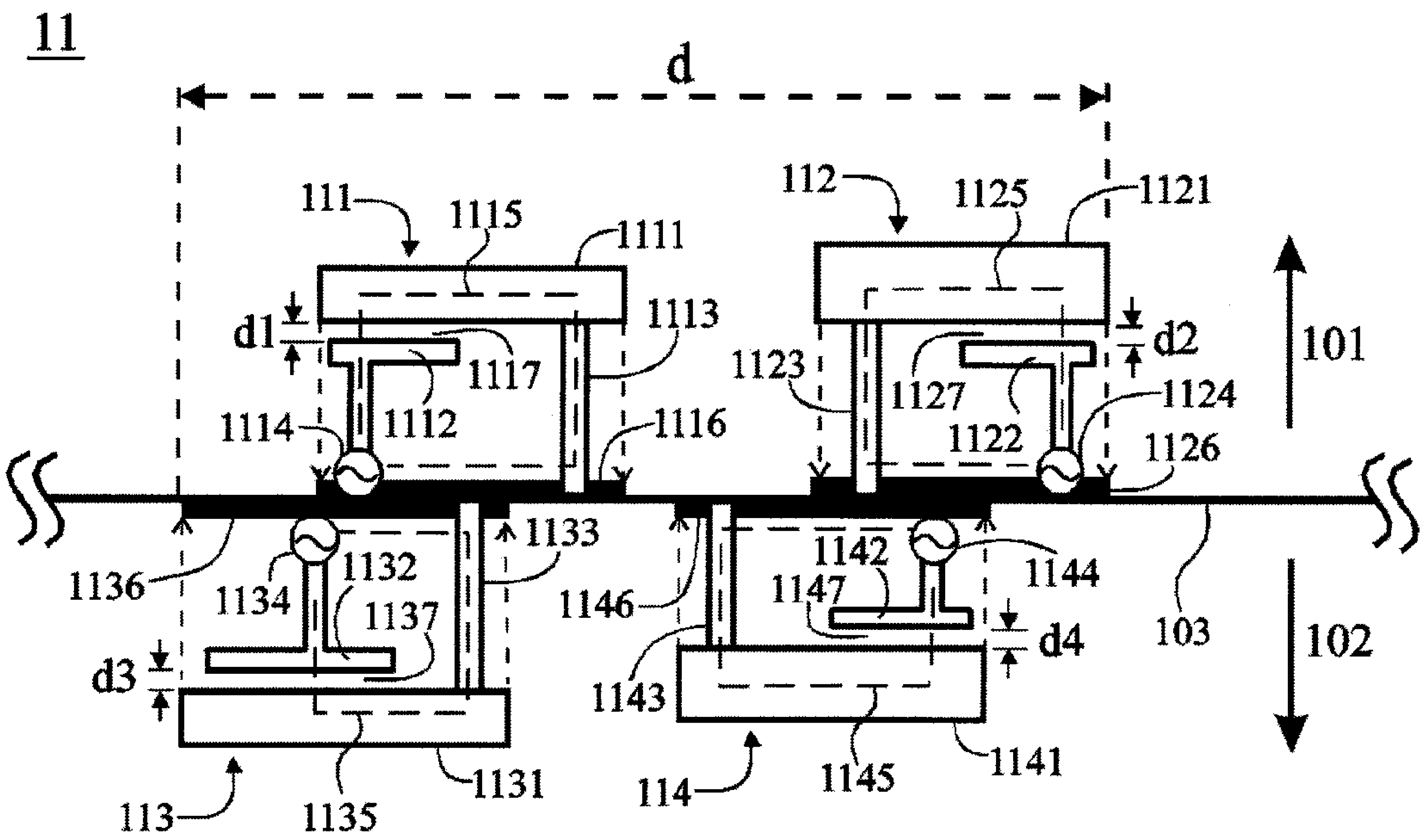
111
1125
1115
103
1135
1145
102
113
114
11

FIG.1A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1127
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1114
1116
1126
1133
1136
1134
1132
1137
1146
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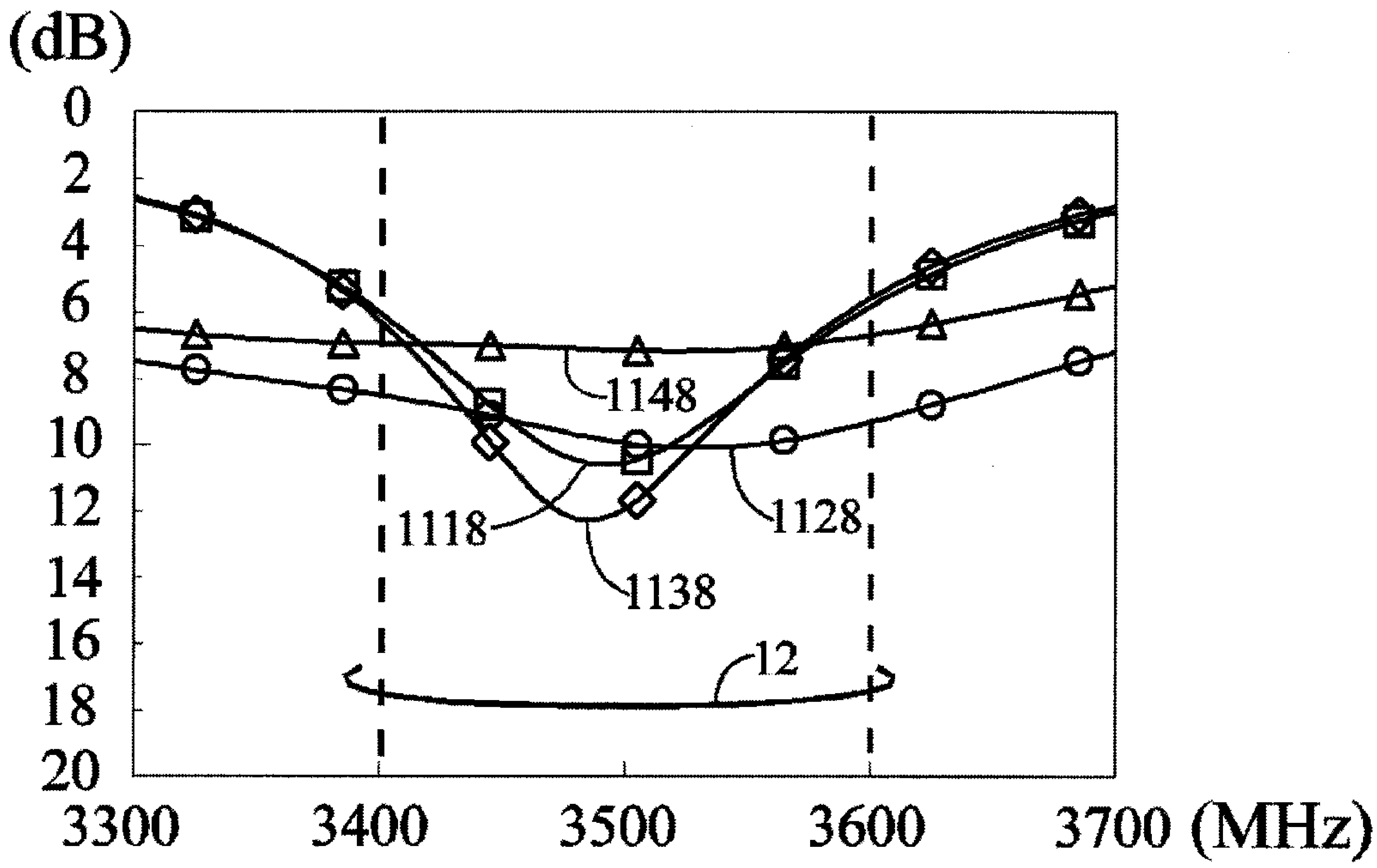
114
1145
1141

FIG.1B


(dB)
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2
4
6
8
10
12
14
16
18
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3300
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3500
3600
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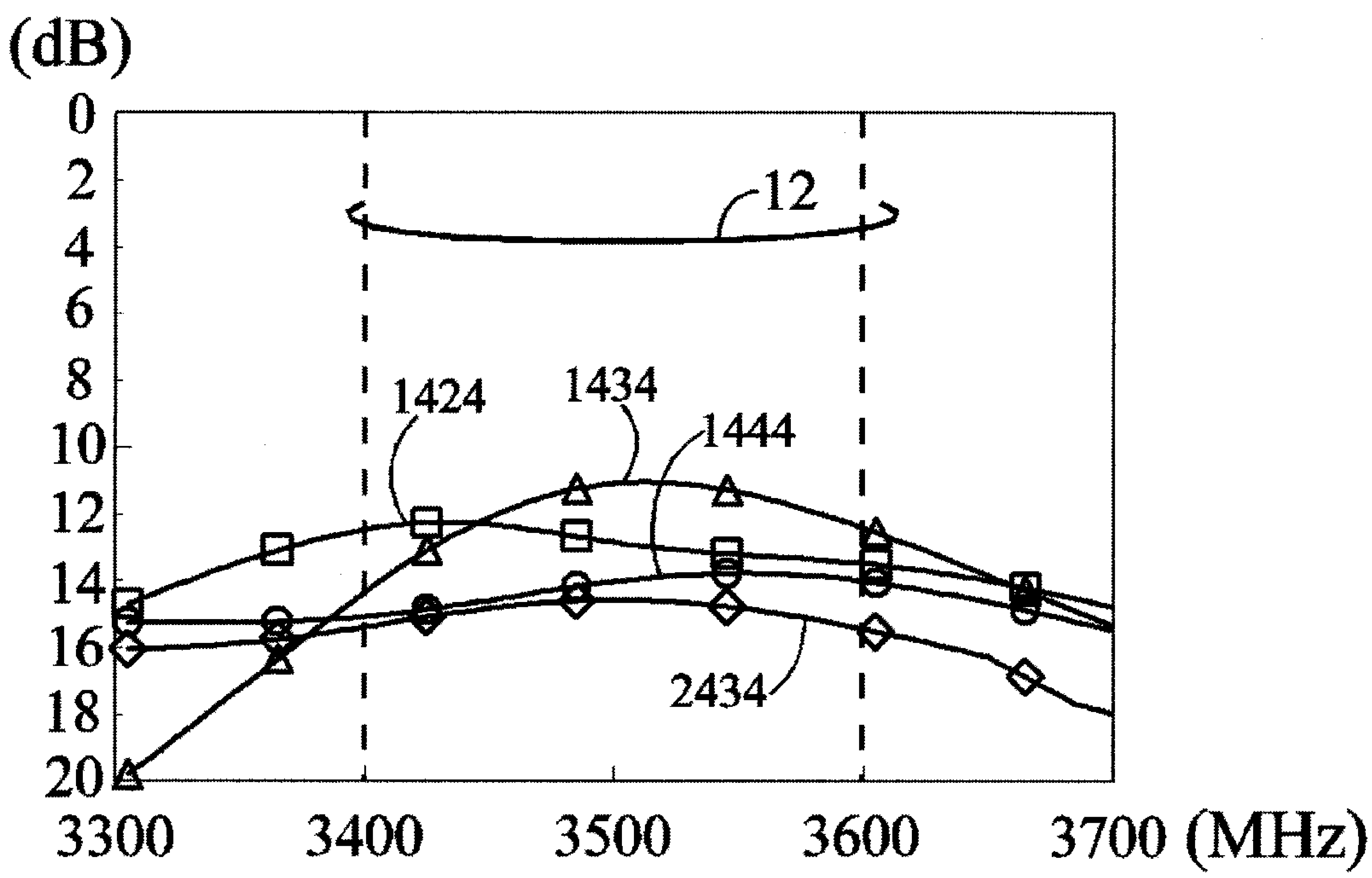
1128
1138
12

FIG.1C


(dB)
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2
4
6
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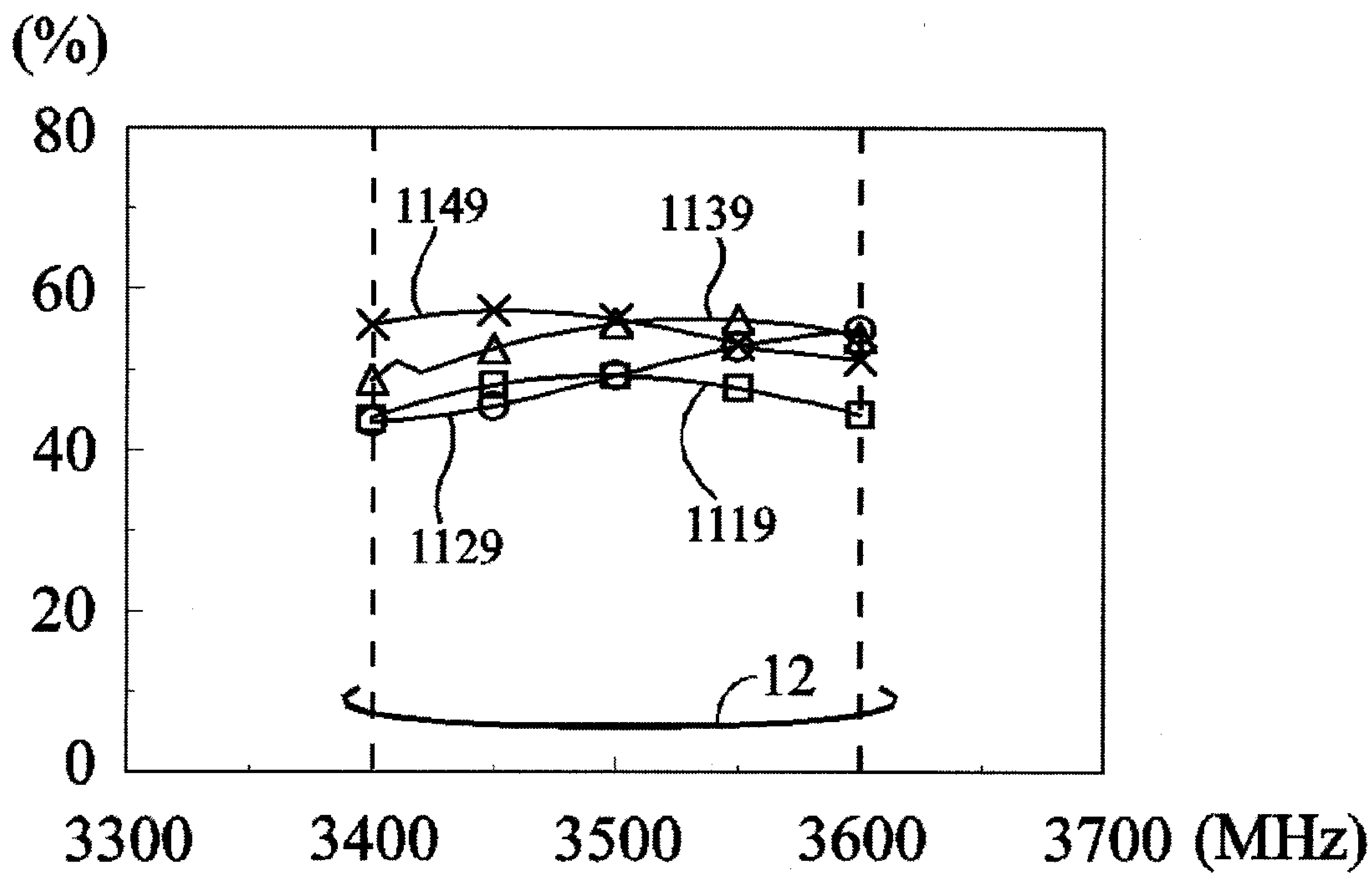
12
14
16
18
20
3300
3400
3500
3600
3700 (MHz)
12
1424
1434
1444
2434

FIG.1D


(%)
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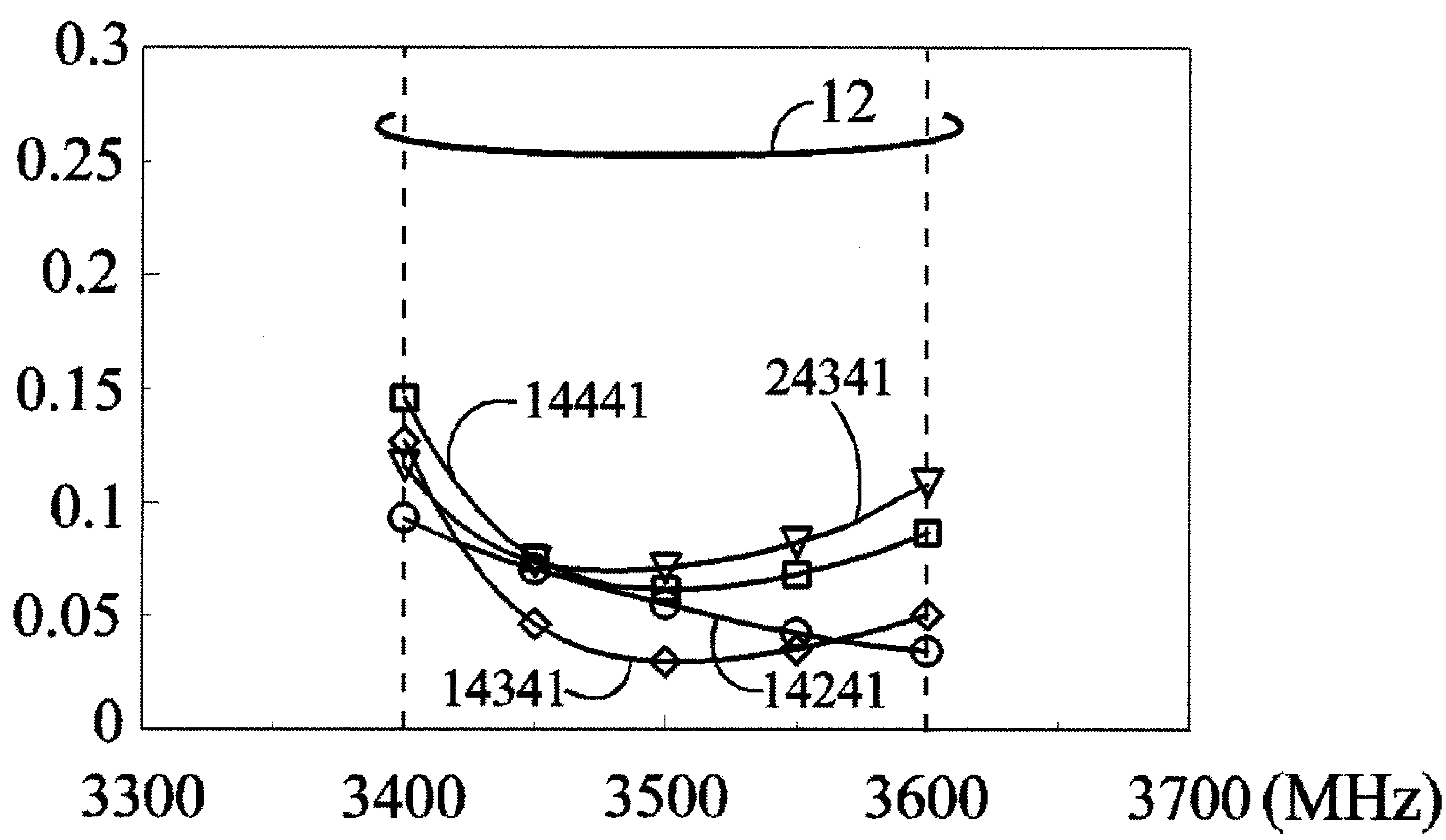
1139
1129
1119
12
3300
3400
3500
3600
3700 (MHz)

FIG.1E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0.25
0.2
0.15
0.1
0.05
0
12
14441
24341
14341
14241
3300
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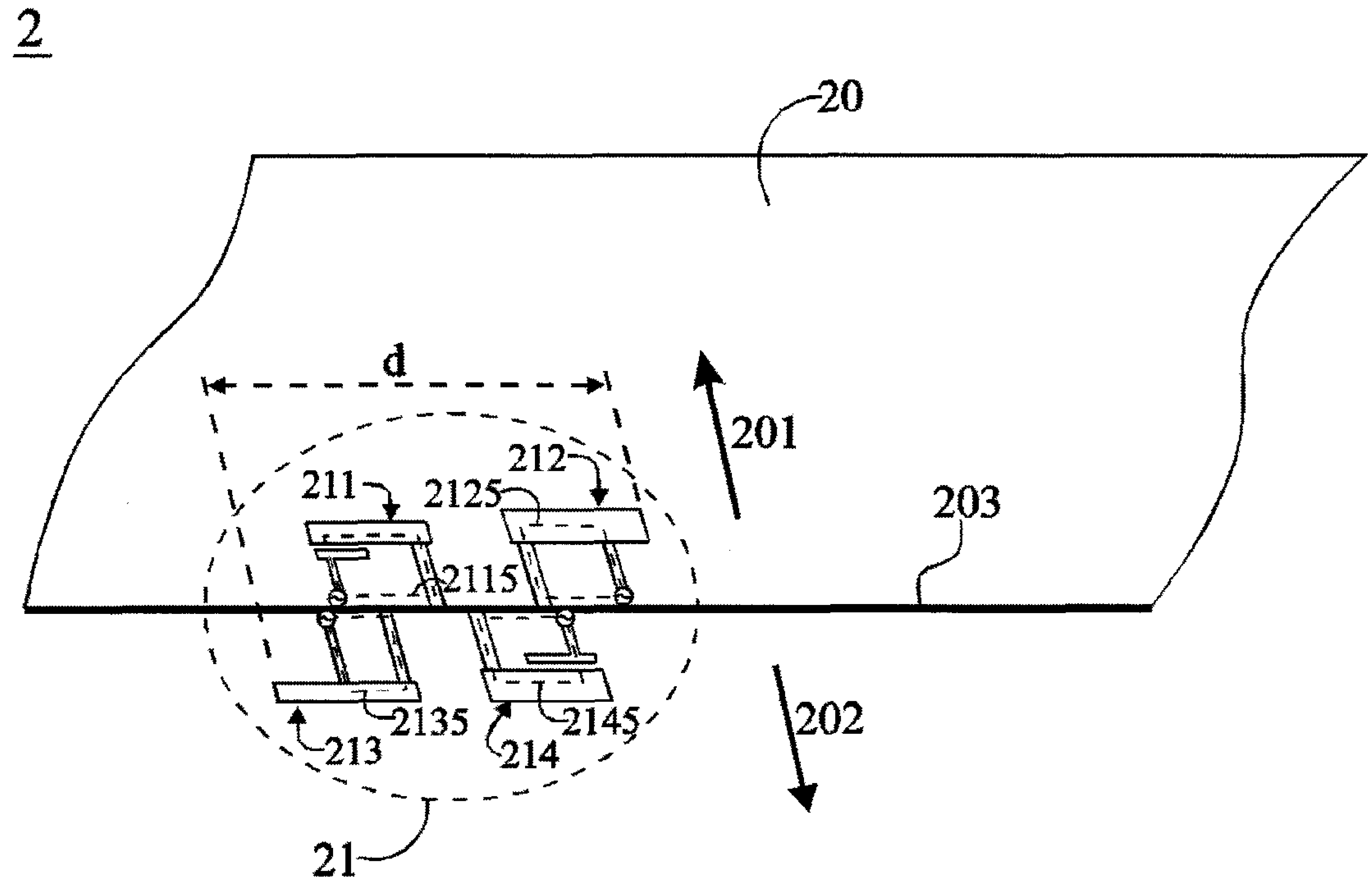
3500
3600
3700 (MHz)

FIG.1F



2
20
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211
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212
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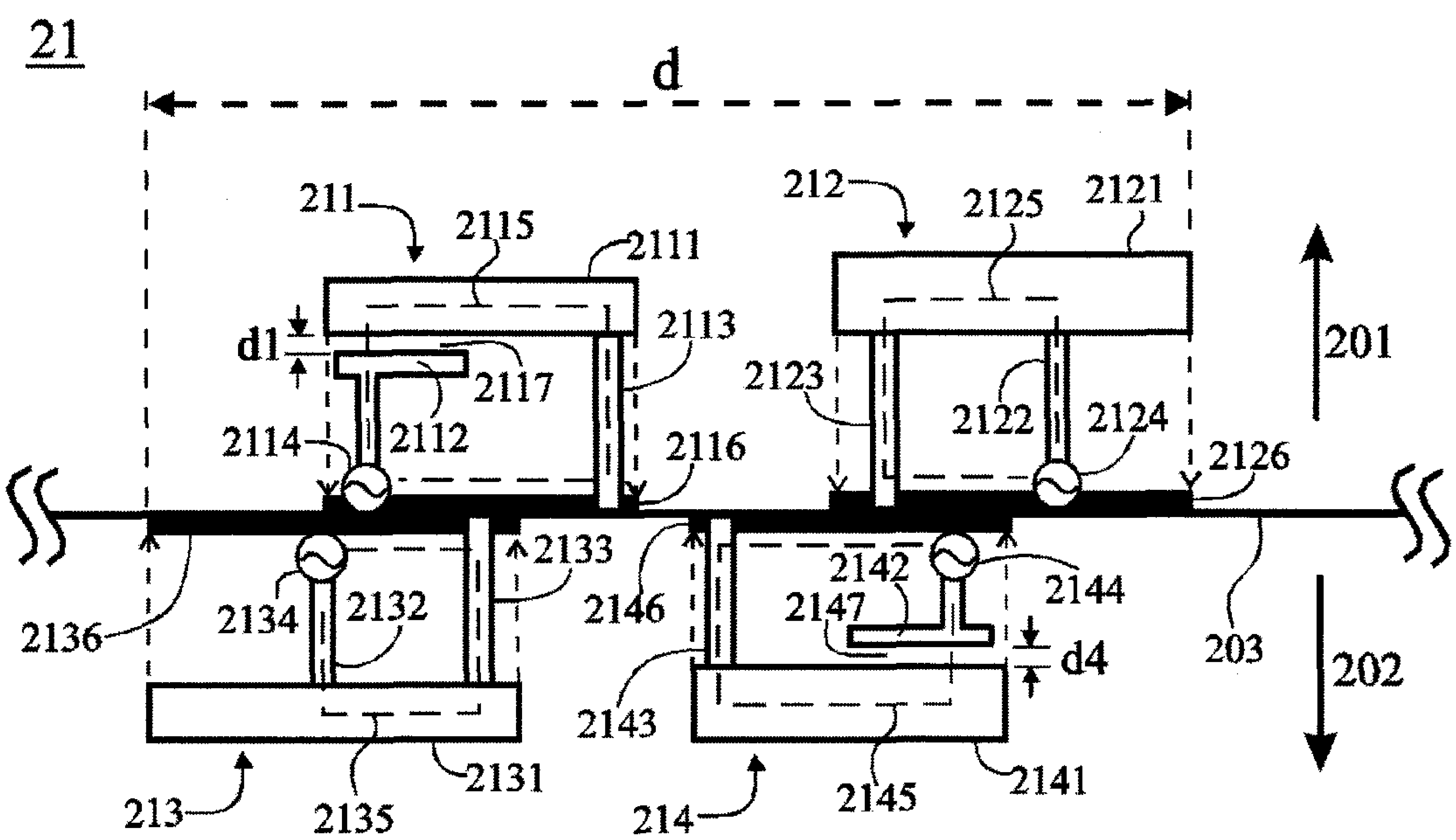
2115
2135
2145
202
213
214
21

FIG.2A



21
d
211
2115
2111
212
2125
2121
201
d1
2113
2117
2123
2122
2124
2112
2114
2116
2126
2133
2142
2144
2136
2134
2132
2146
2147
d4
203
202
2143
2135
2131
2145
2141
213
214

FIG.2B

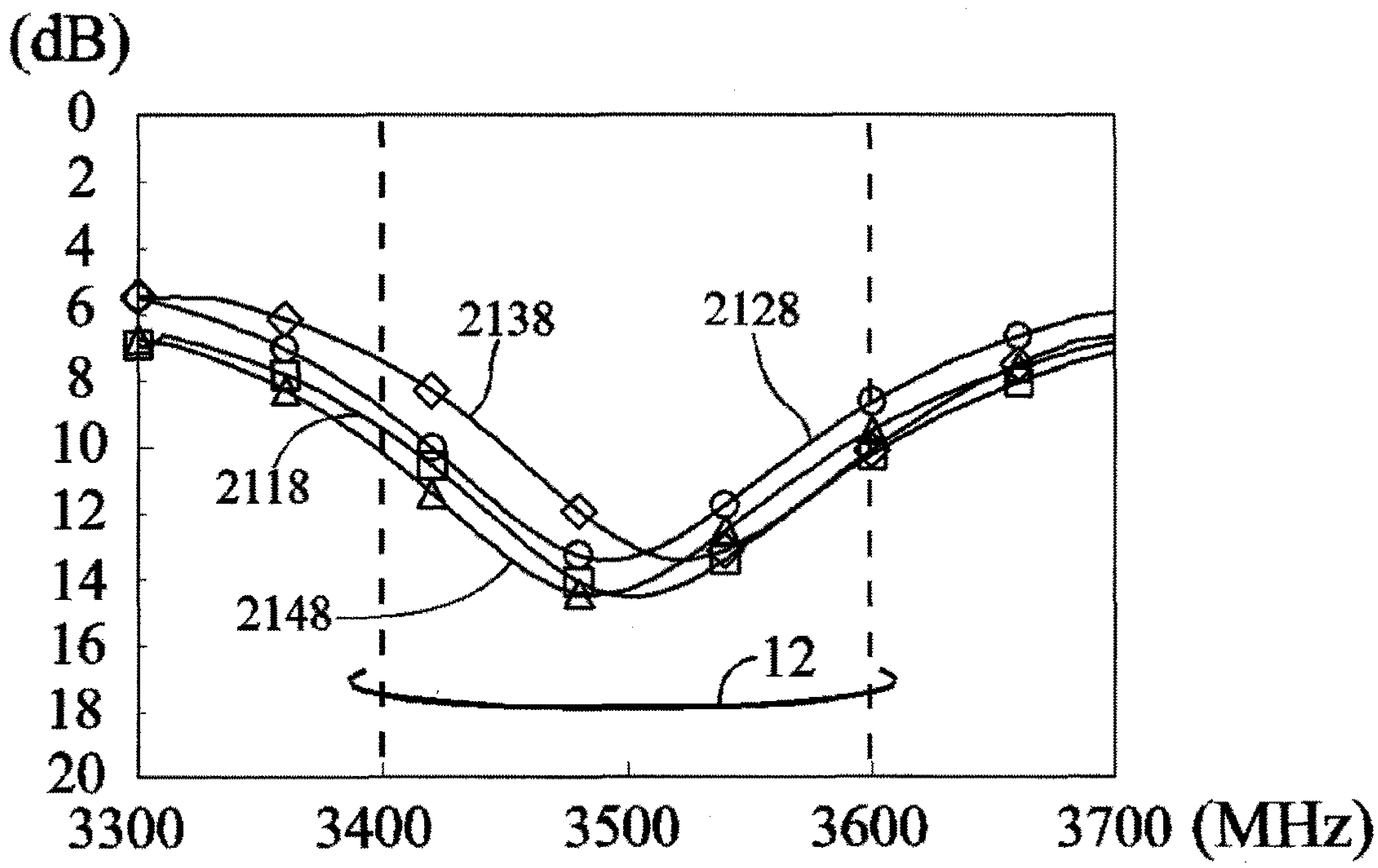

(dB)
0
2
4
6
8
10
12
14
16
18
20
3300
3400
3500
3600
3700 (MHz)
2138
2128
2118
2148
12

FIG.2C

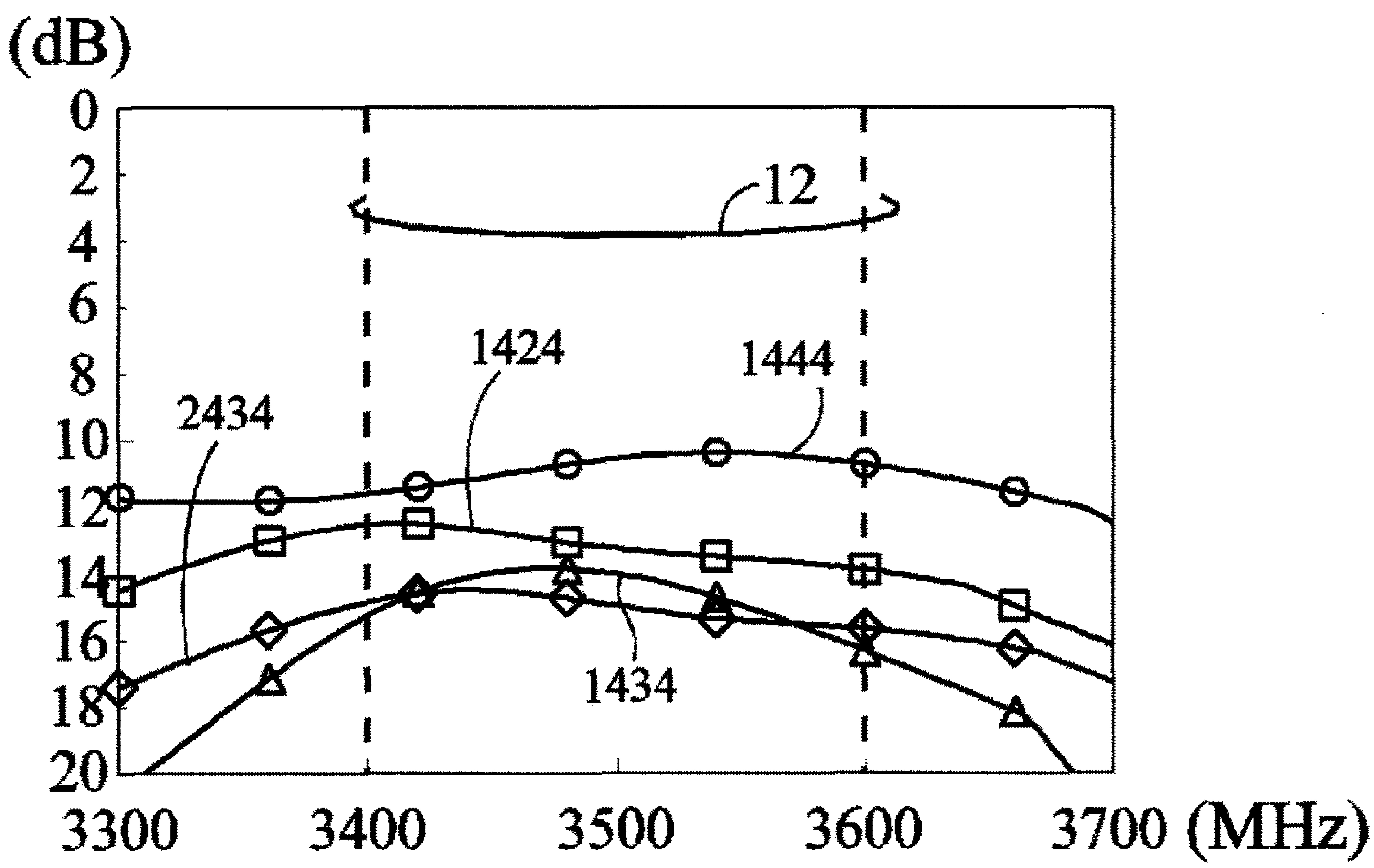
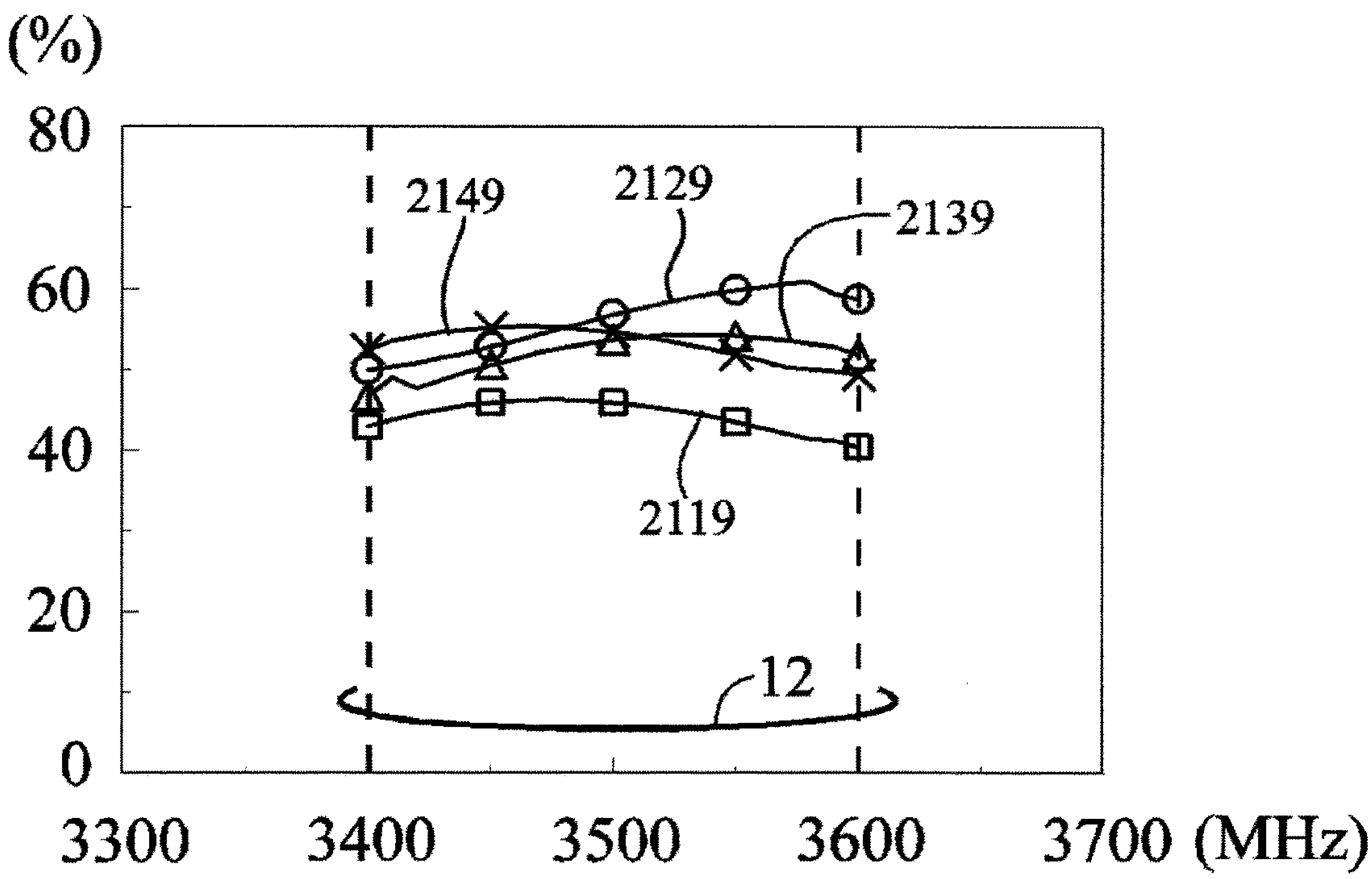

(dB)
0
2
4
6
8
10
12
14
16
18
20
3300
3400
3500
3600
3700 (MHz)
12
1424
1444
2434
1434

FIG.2D


(%)
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60
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20
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2129
2139
2119
12
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3500
3600
3700 (MHz)

FIG.2E

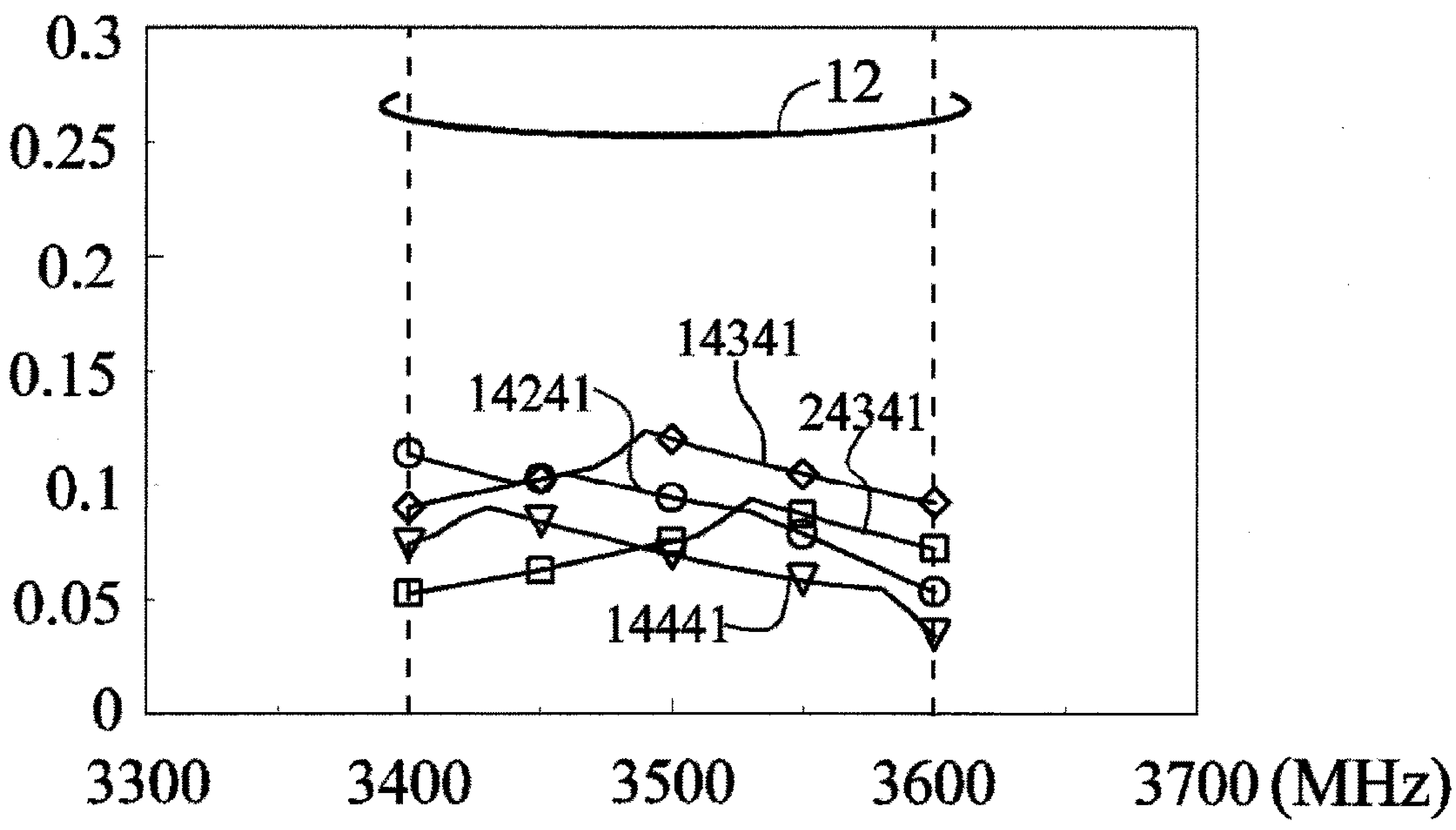

0.3
0.25
0.2
0.15
0.1
0.05
0
12
14341
14241
24341
14441
3300
3400
3500
3600
3700 (MHz)

FIG.2F

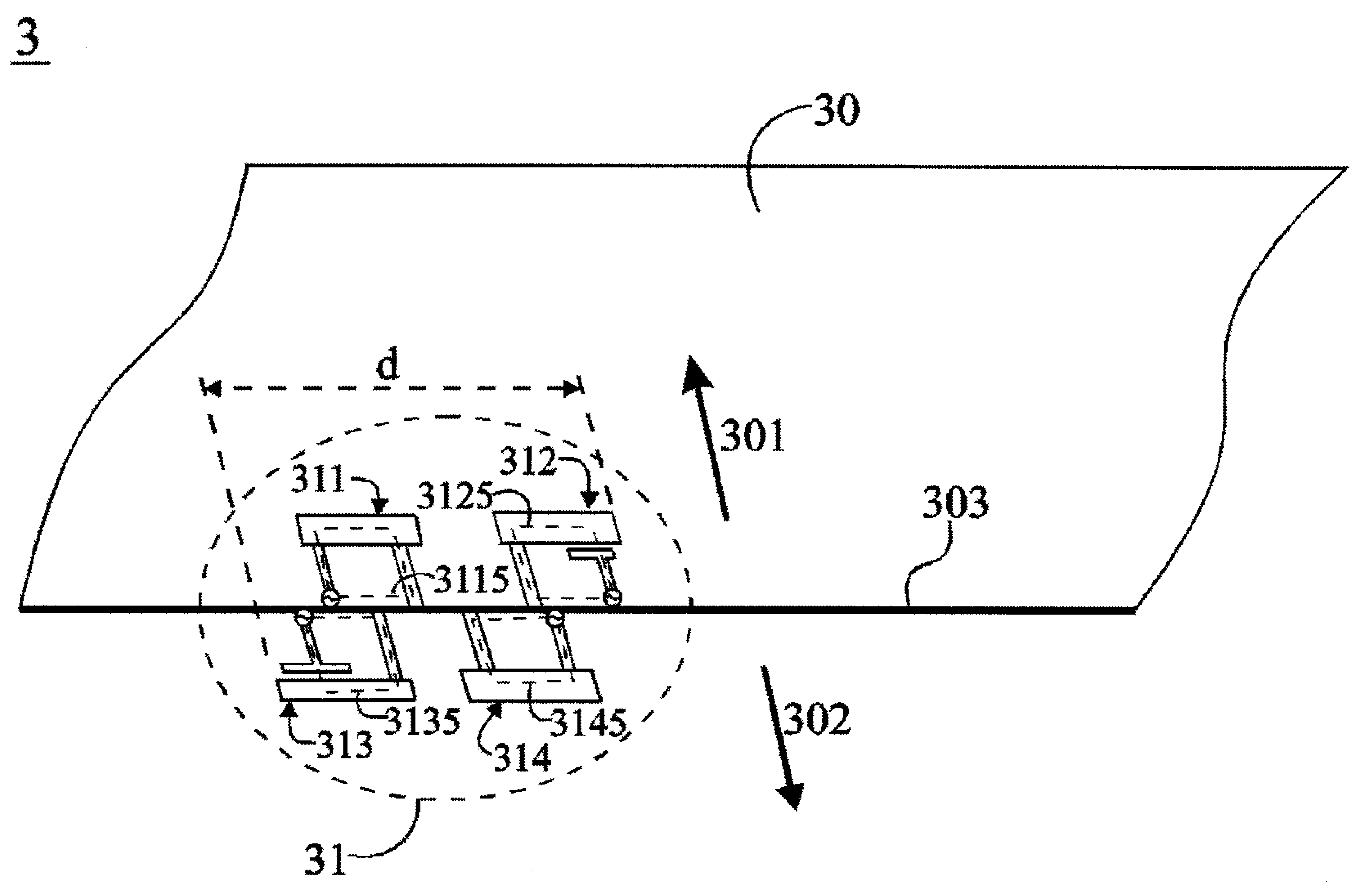
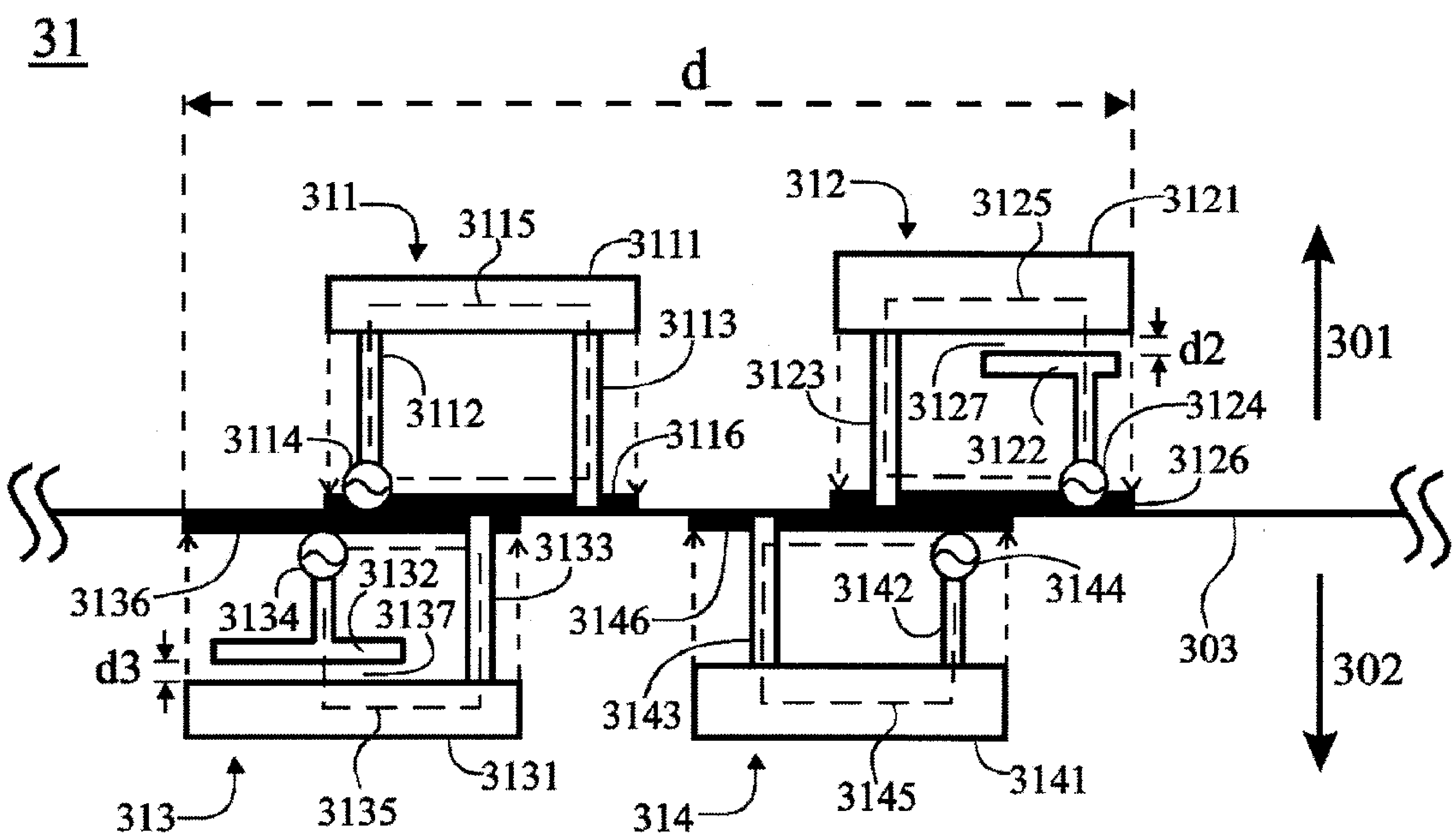

3
30
d
301
311
312
3125
3115
303
313
3135
314
3145
302
31

FIG.3A


31
d
311
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312
3125
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3113
d2
3112
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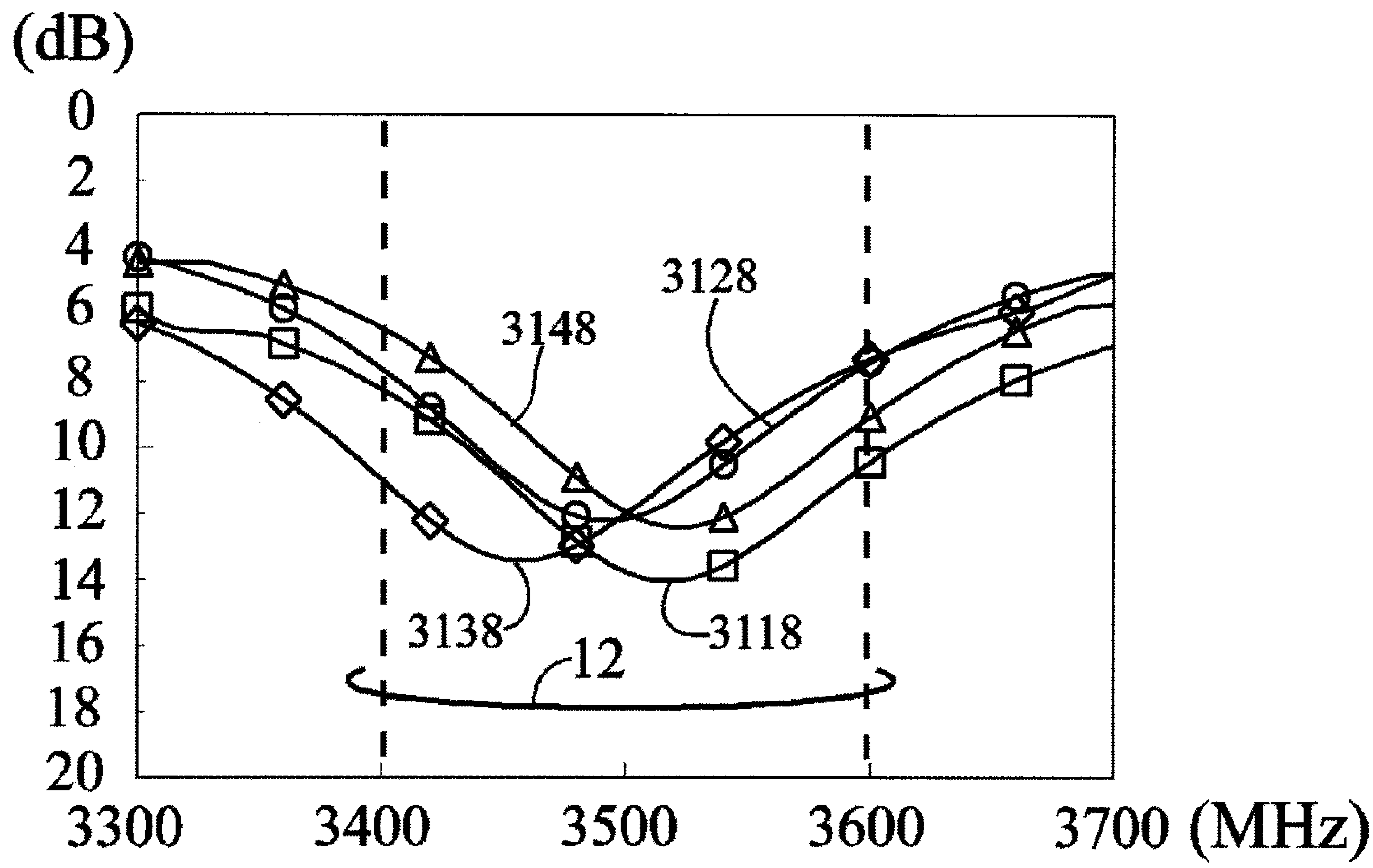
3127
3124
3114
3116
3122
3126
3133
3136
3132
3134
3137
3146
3142
3144
303
302
d3
3143
313
3135
3131
314
3145
3141

FIG.3B


(dB)
0
2
4
6
8
10
12
14
16
18
20
3300
3400
3500
3600
3700 (MHz)
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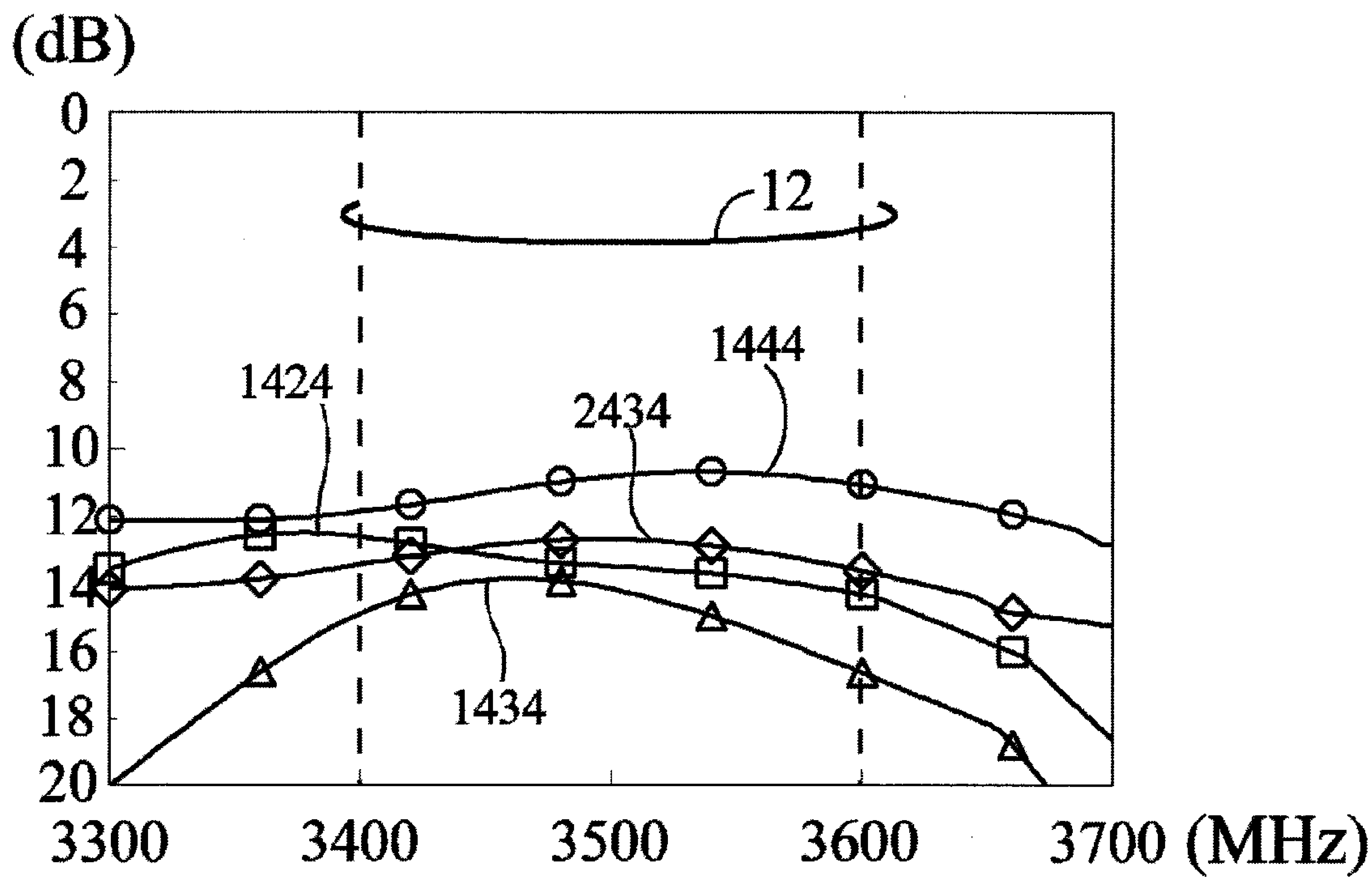
3148
3138
3118
12

FIG.3C


(dB)
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4
6
8
10
12
14
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3300
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3500
3600
3700 (MHz)
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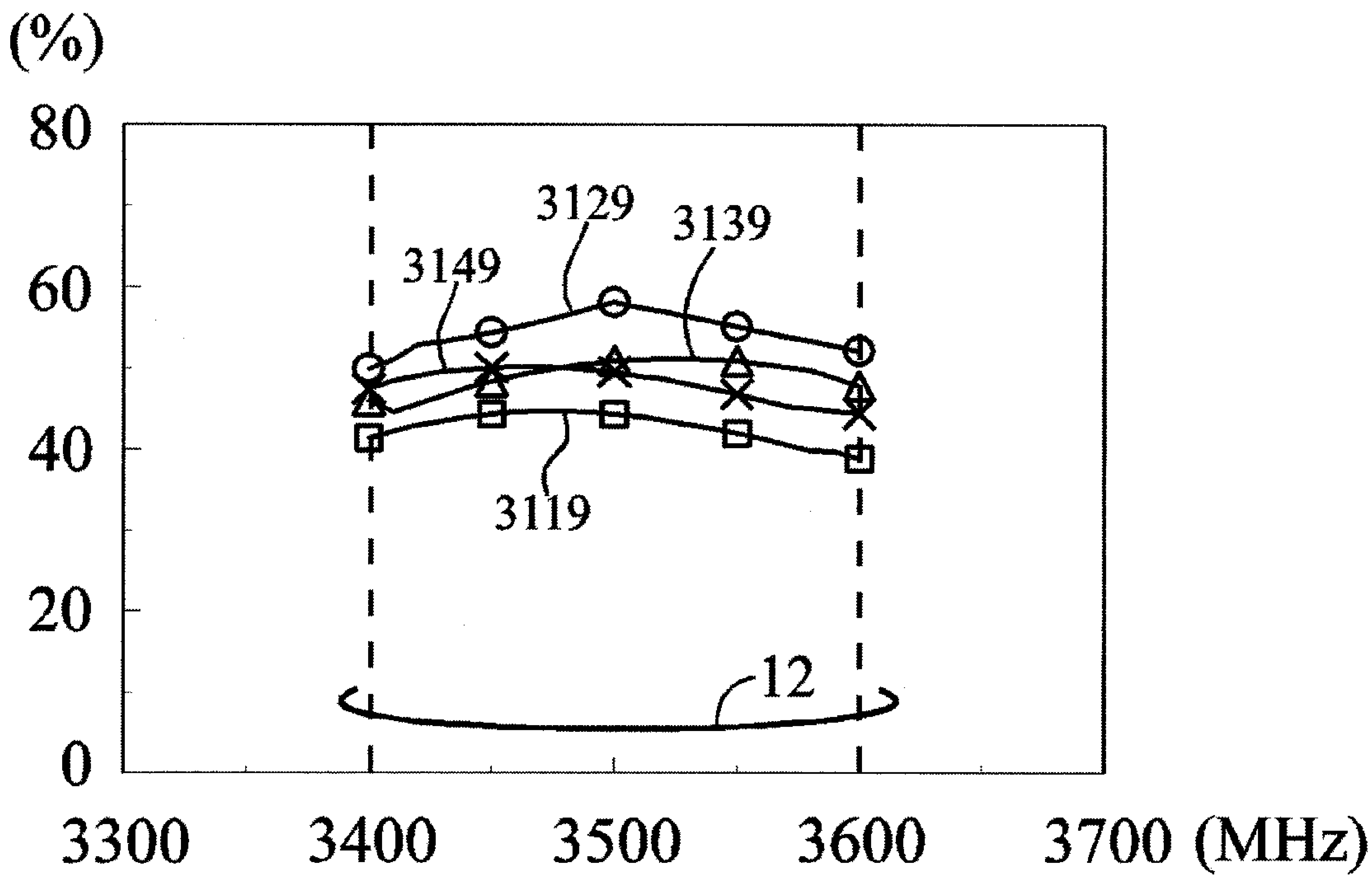
1444
1424
2434
1434

FIG.3D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3700 (MHz)
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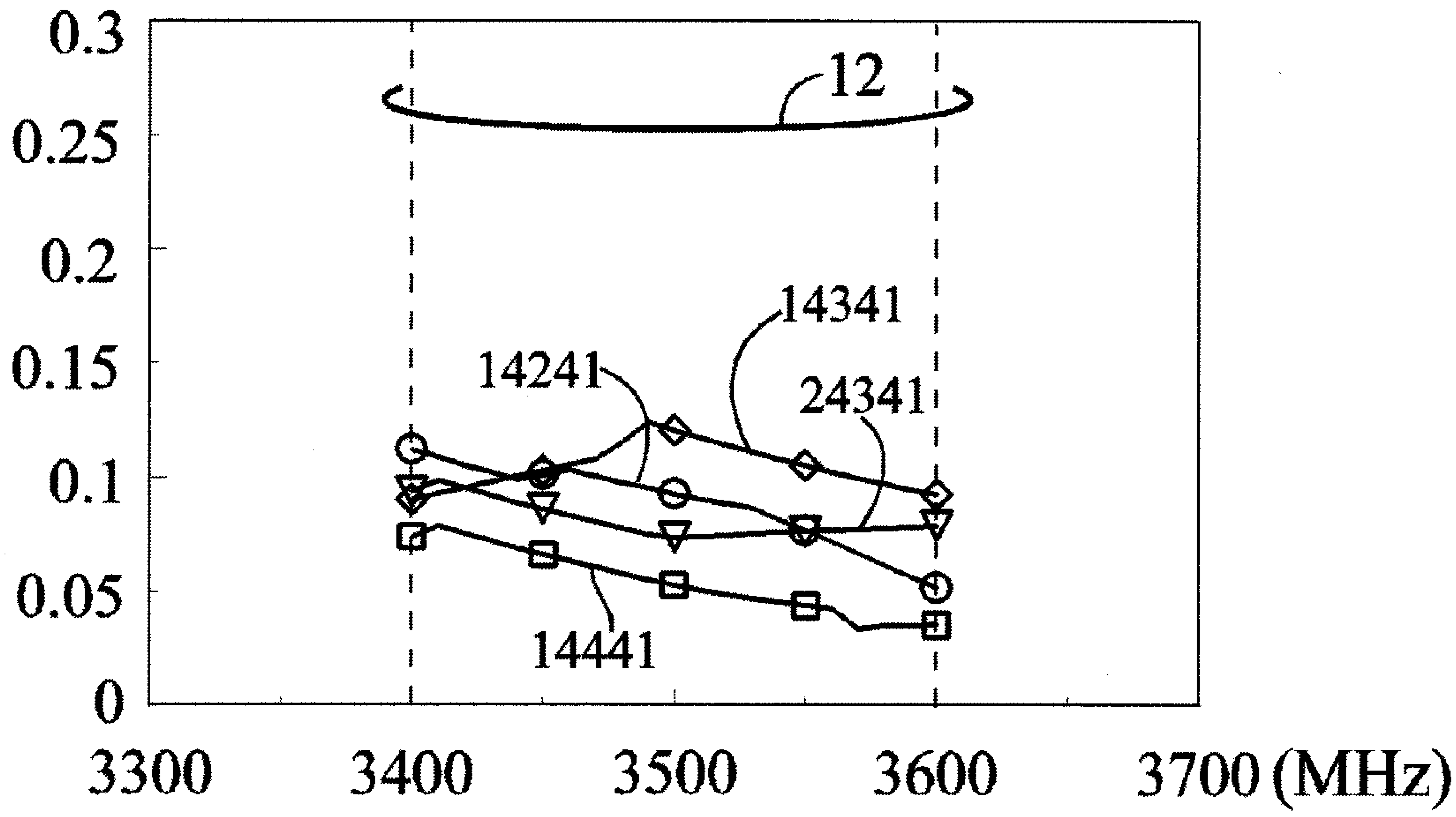
3139
3149
3119
12

FIG.3E


0.3
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3600
3700 (MHz)
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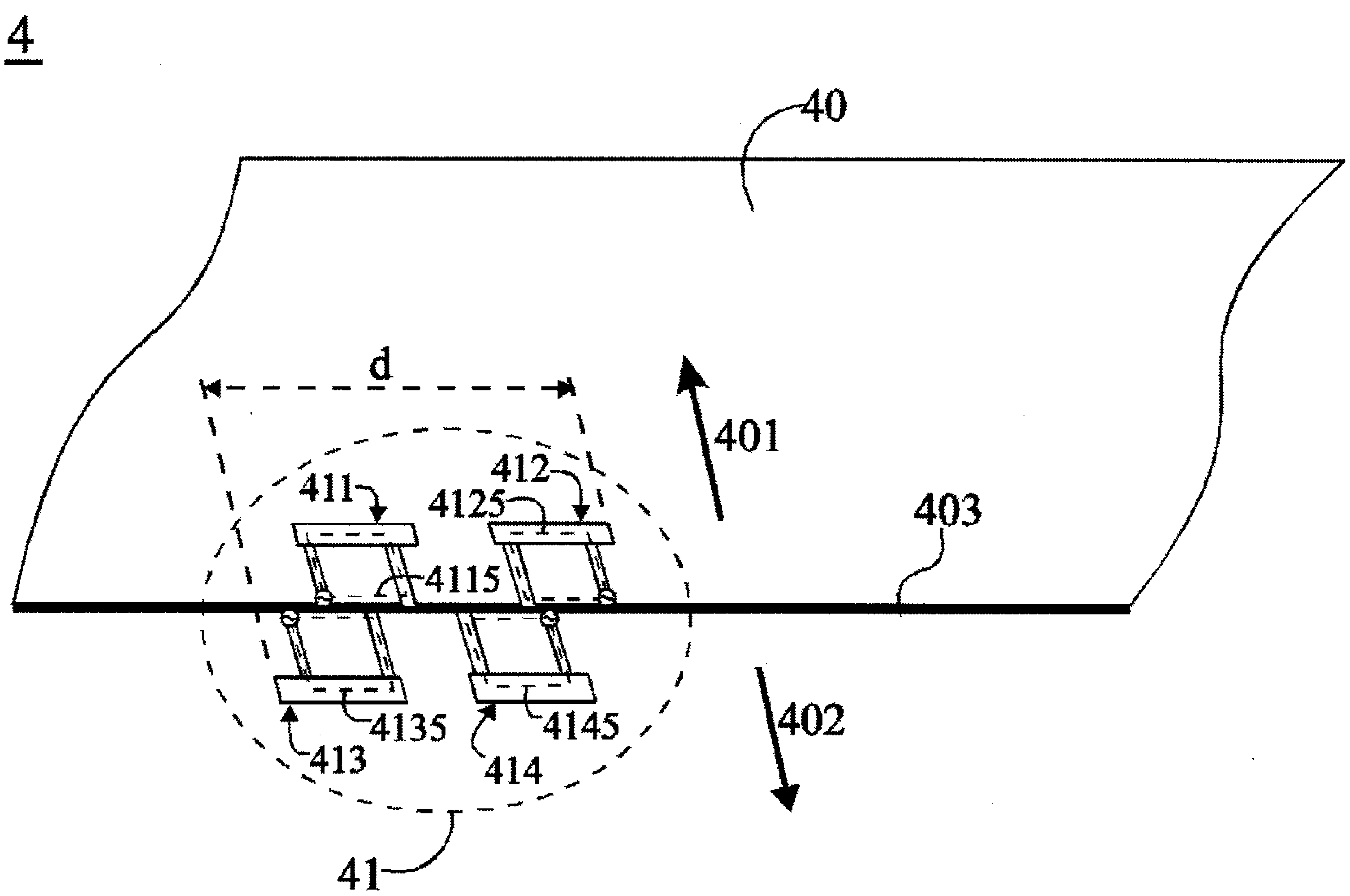
24341
14441

FIG.3F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401
411
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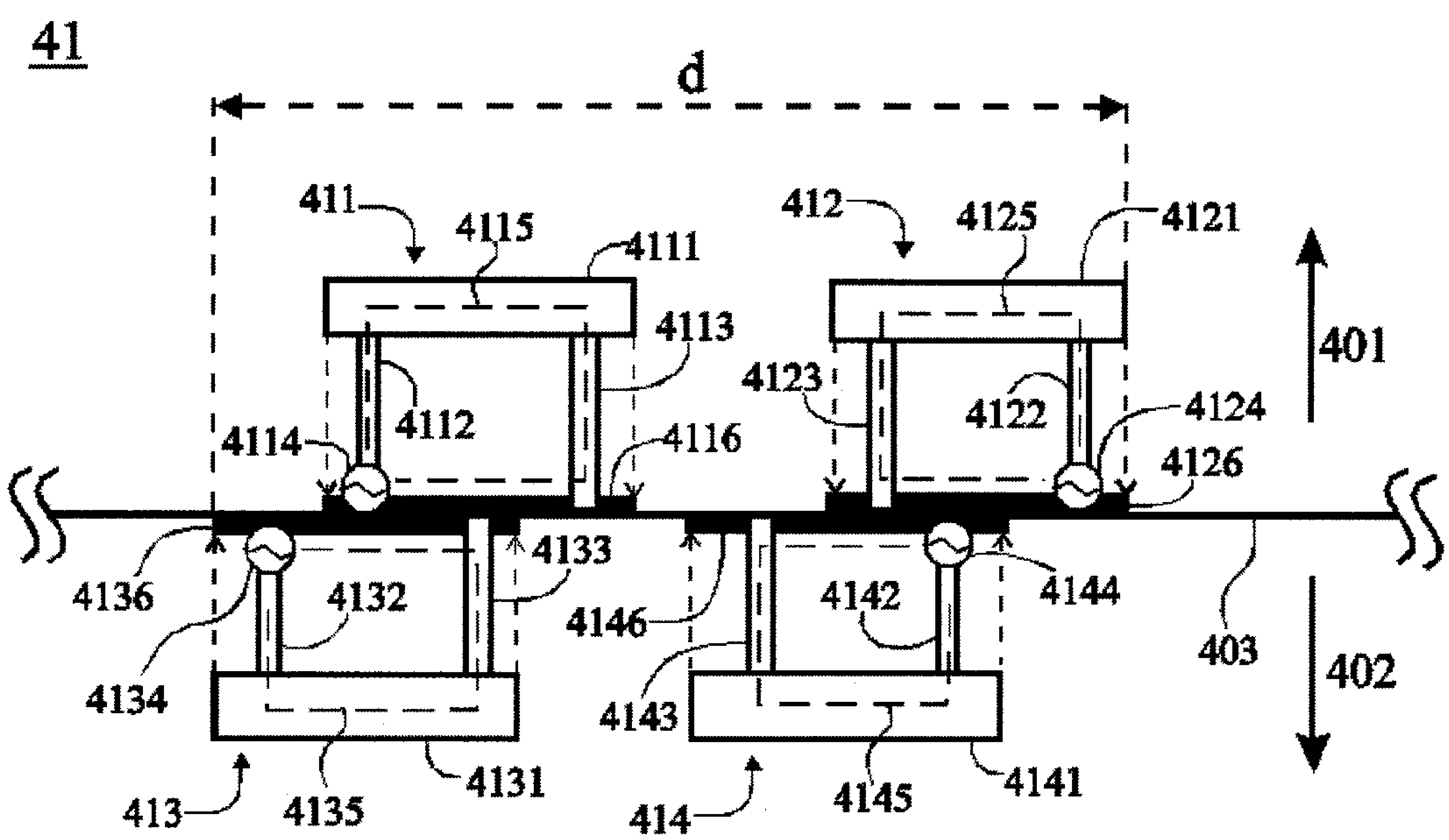
4125
4115
403
4135
4145
402
413
414
41

FIG.4A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4121
4113
401
4123
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4126
4136
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403
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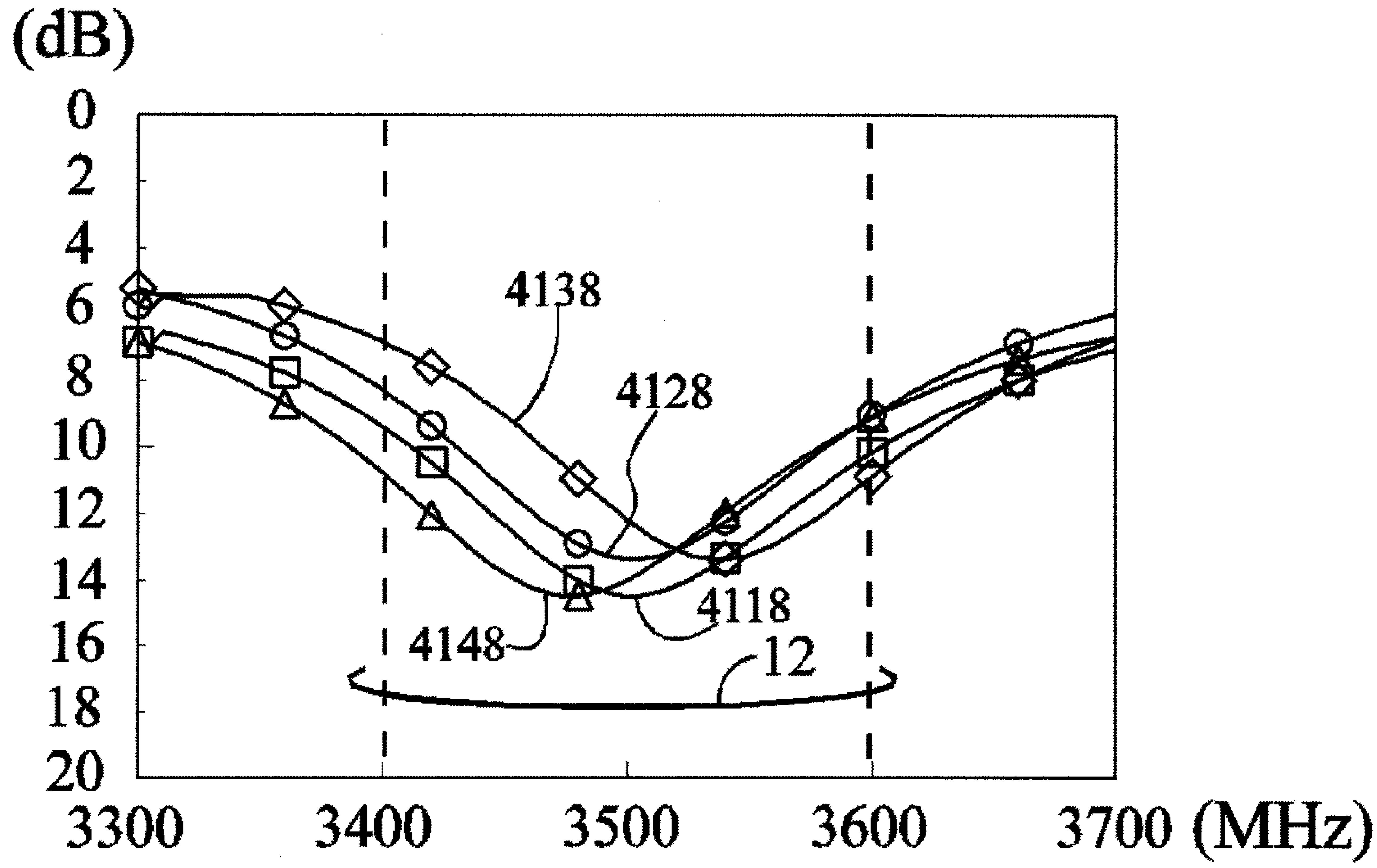
4143
402
413
4135
4131
414
4145
4141

FIG.4B



(dB)
0
2
4
6
8
10
12
14
16
18
20
3300
3400
3500
3600
3700 (MHz)
4138
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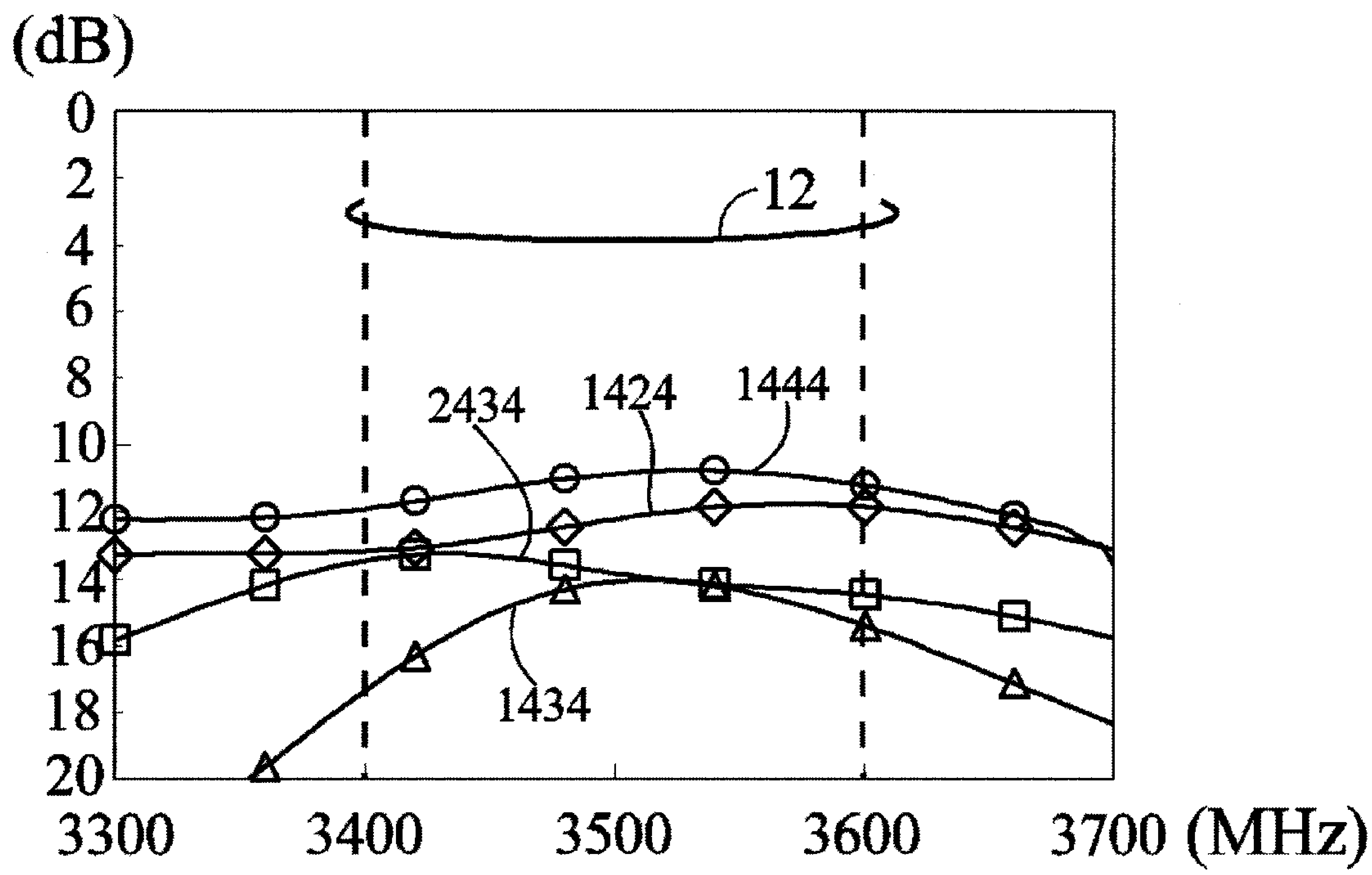
4118
4148
12

FIG.4C



(dB)
0
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4
6
8
10
12
14
16
18
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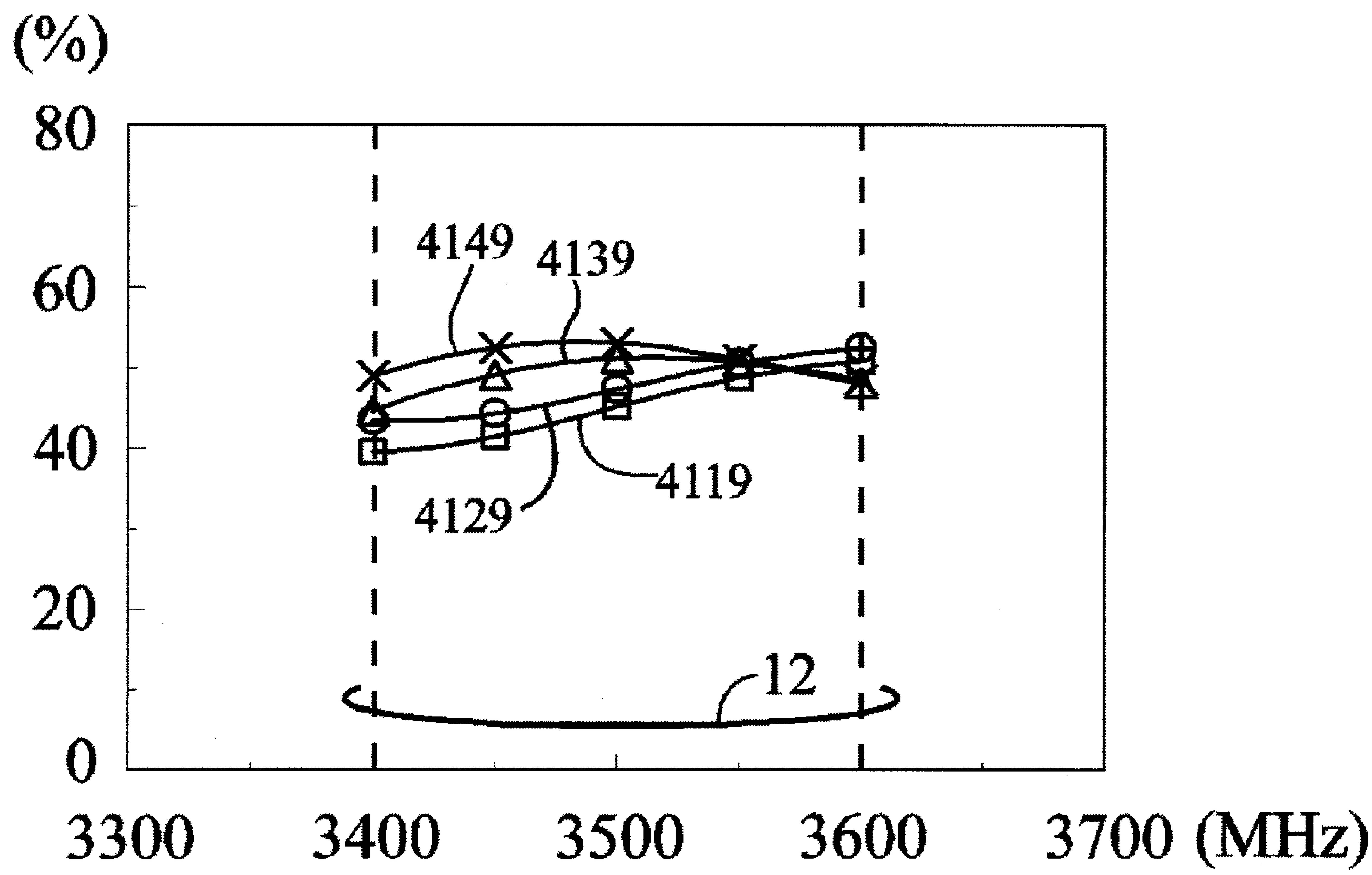
3300
3400
3500
3600
3700 (MHz)
12
2434
1424
1444
1434

FIG.4D


(%)
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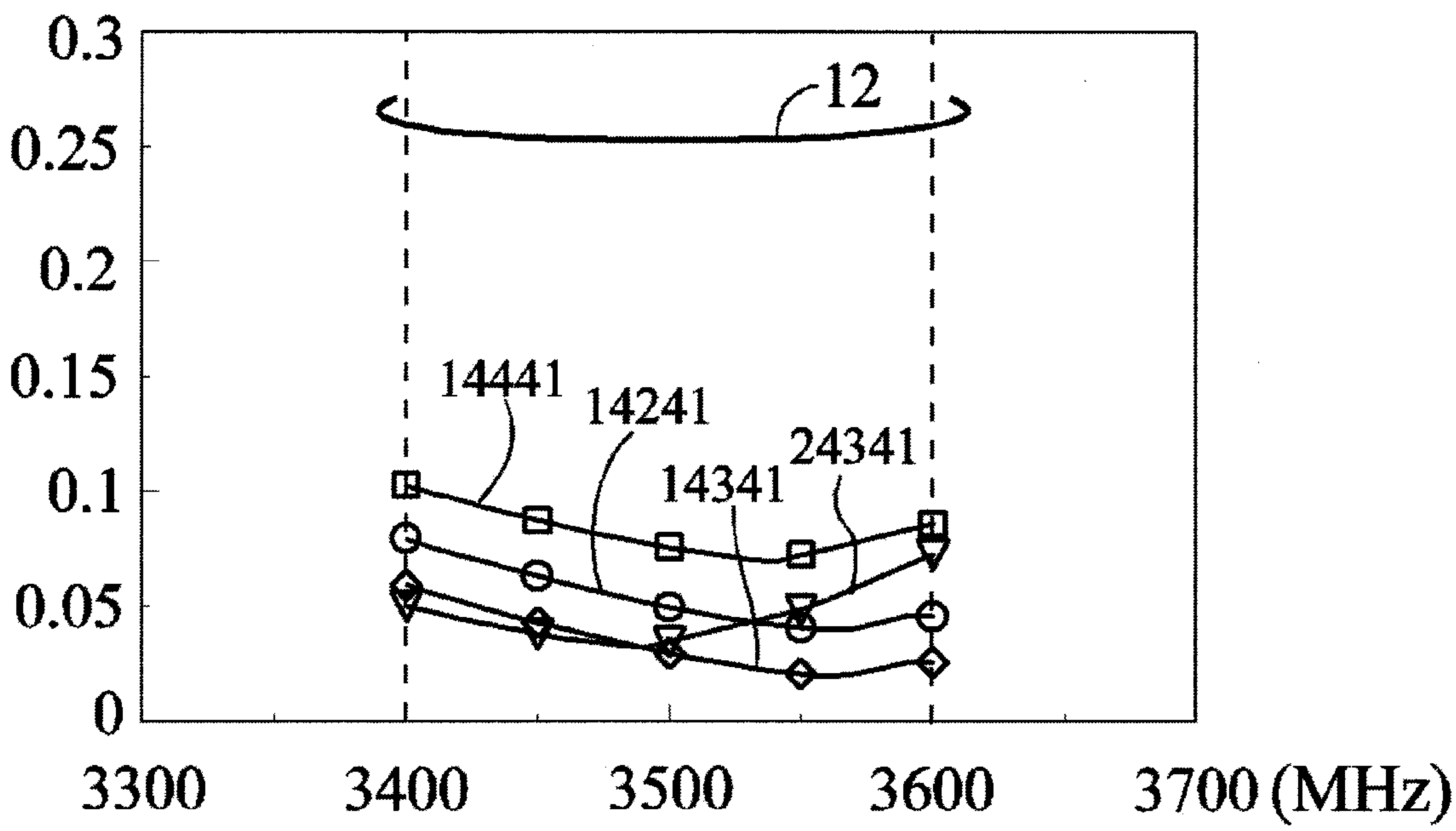
4139
4119
4129
12
3300
3400
3500
3600
3700 (MHz)

FIG.4E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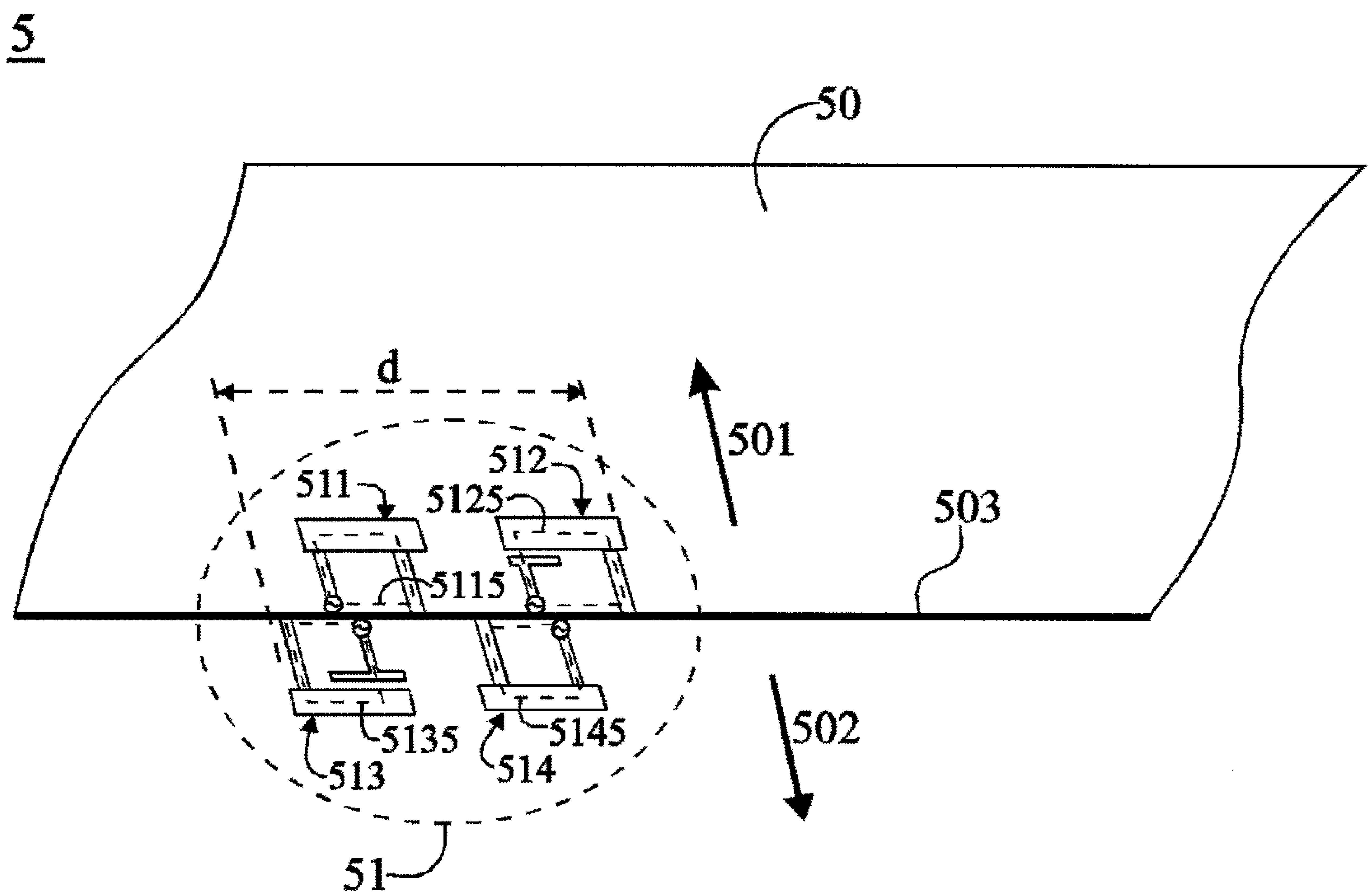
3600
3700 (MHz)

FIG.4F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501
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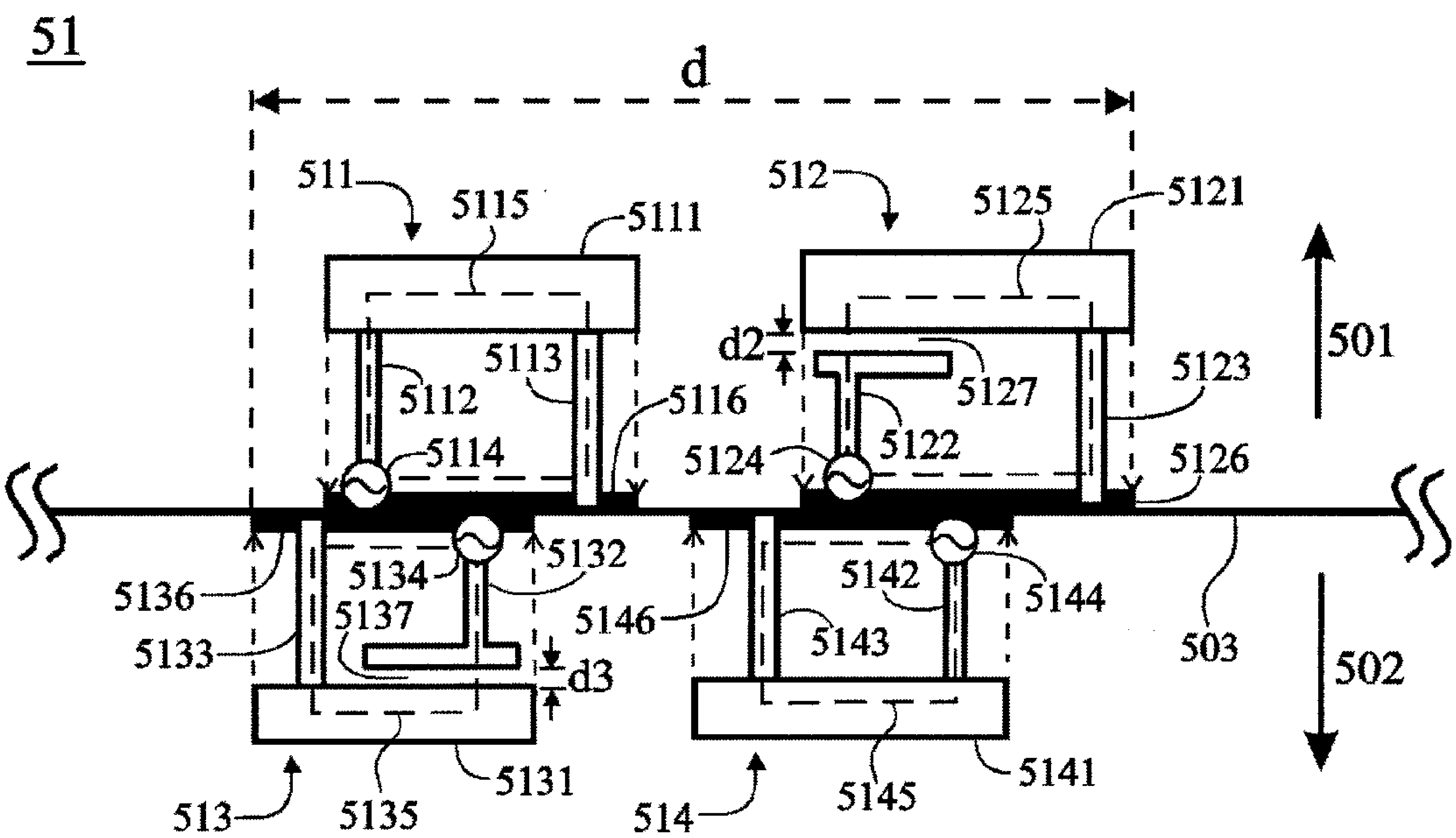
5145
502
513
514
51

FIG.5A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5134
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5141
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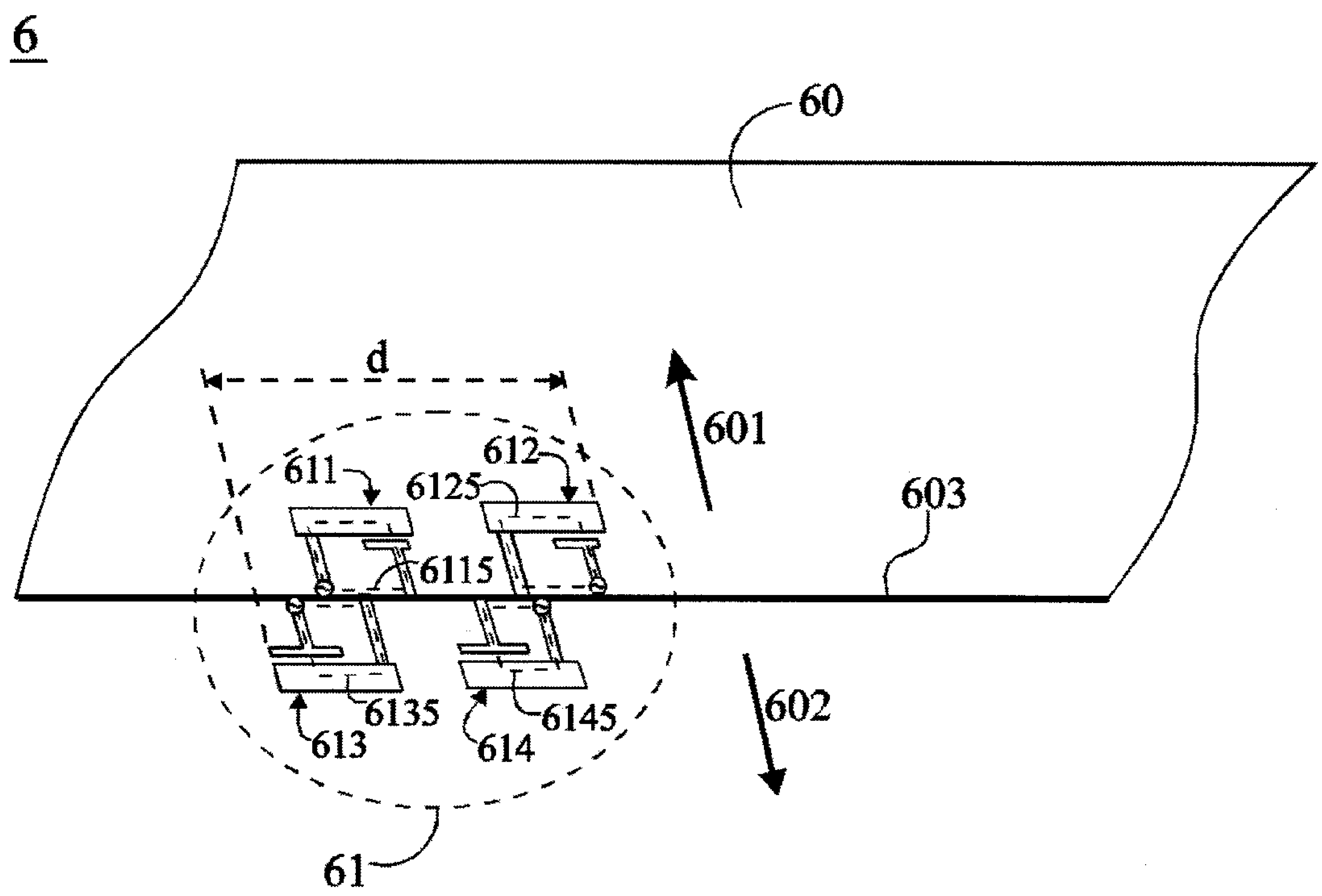
FIG.5B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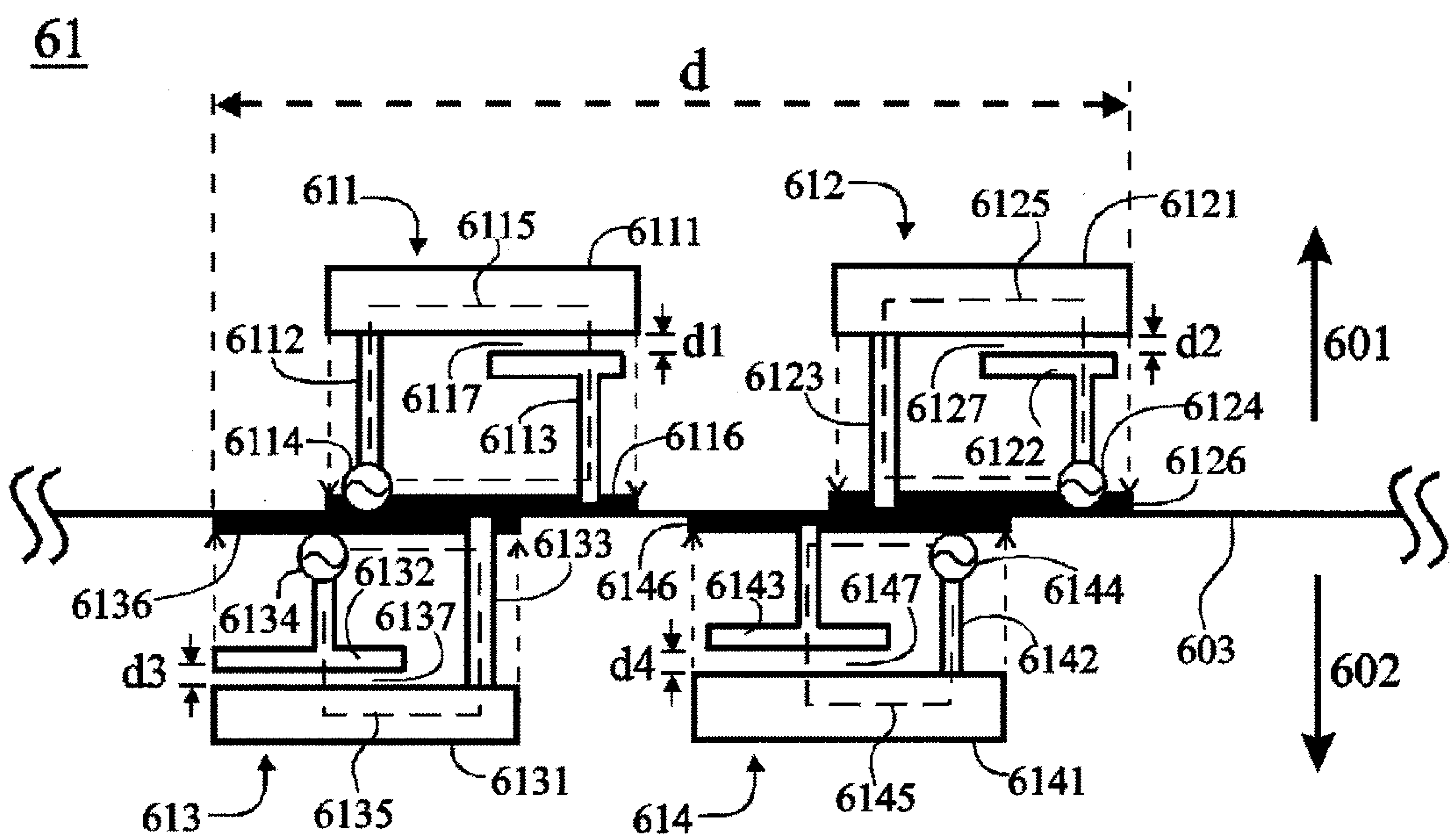
61

FIG.6A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d2
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6122
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6136
6133
6132
6134
6137
6146
6143
6147
6144
603
d3
d4
6142
602
6135
6131
613
614
6145
6141

FIG.6B

MULTI-ANTENNA COMMUNICATION DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims under 35 U.S.C. § 119(a) the benefit of Taiwanese Patent Application No. 105143339 filed Dec. 27, 2016, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

The disclosure relates to communication devices, and relates to a multi-antenna communication device that increases data transmission speed/throughput.

BACKGROUND

The demands for better quality of signals in wireless communication and higher transmission speed/throughput fuel the rapid development of multi-antenna array technology that is applicable to communication devices, such as Multi-Input Multi-Output (MIMO) antenna system or beamforming antenna array system technology. MIMO antenna system has the potential to increase spectrum efficiency and significantly increase channel capacity and data transmission speed. It also has the potential to enhance the reliability of receiving signals at the terminal communication devices. It has become one of the promising technology candidates used in upcoming fifth generation (5G) mobile communication system. For example, under an 8×8 MIMO system, the spectrum efficiency may reach about 37 bps/Hz (20 dB signal-to-noise ratio condition), which is about 4 times that of a 2×2 MIMO system.

However, it remains a challenge to realize a multi-antenna array system in a single space-limited handheld communication device while achieving good radiation characteristic and antenna efficiency for each individual antenna. This would be an important issue need to be solved in the near future. When a plurality of antennas operating in the same frequency band are co-designed and integrated in a communication device with limited space, the envelope correlation coefficient (ECC) between the multiple antennas would greatly increase, resulting in attenuation of the antenna radiation performance and a reduction in the speed/throughput of data transmission, making integration of multi-antenna design a challenging task.

Some previous technology documents have proposed a design scheme that increases energy isolation between multiple antennas by providing a protruding or recessed structure on a ground plane between the multiple antennas as an energy isolator. However, such a design may lead to excitation of additional coupling currents, causing an increase in the correlation coefficients between the multiple antennas, and possibly an increase in the overall size of the multi-antenna array. This is not desirable for commercial terminal communication devices, which require high efficiency and downsized multi-antenna array designs.

Therefore, there is a need for a design that solve the above-mentioned problems in order to meet the demand for high data transmission speed/throughput in future multi-antenna communication devices.

SUMMARY

According to an embodiment, the disclosure provides a multi-antenna communication device, which may include a grounding conductor plane and a four-antenna array. The grounding conductor plane separates a first side space and a second side space opposite to the first side space, and includes a first edge. The four-antenna array may be located at the first edge and has an overall maximum array length extending along the first edge. The four-antenna array may include a first antenna, a second antenna, a third antenna and a fourth antenna. The first antenna may be located in the first side space, and include a first feeding conductor line, a first grounding conductor line, and a first radiating conductor portion electrically connected with a first signal source via the first feeding conductor line and electrically connected with the first edge via the first grounding conductor line, thereby forming a first loop path and generating at least one first resonant mode. The first radiating conductor portion has a first projection line segment at the first edge. The second antenna may be located in the first side space, and include a second feeding conductor line, a second grounding conductor line, and a second radiating conductor portion electrically connected with a second signal source via the second feeding conductor line and electrically connected with the first edge via the second grounding conductor line, thereby forming a second loop path and generating at least one second resonant mode. The second radiating conductor portion has a second projection line segment at the first edge. The third antenna may be located at the second side space, and include a third feeding conductor line, a third grounding conductor line, and a third radiating conductor portion electrically connected with a third signal source via the third feeding conductor line and electrically connected with the first edge via the third grounding conductor line, thereby forming a third loop path and generating at least one third resonant mode. The third radiating conductor portion has a third projection line segment at the first edge. The fourth antenna may be located at the second side space, and include a fourth feeding conductor line, a fourth grounding conductor line, and a fourth radiating conductor portion electrically connected with a fourth signal source via the fourth feeding conductor line and electrically connected with the first edge via the fourth grounding conductor line, thereby forming a fourth loop path and generating at least one fourth resonant mode. The fourth radiating conductor portion has a fourth projection line segment at the first edge. The first projection line segment and the third projection line segment partially overlapped. The second projection line segment and the fourth projection line segment are partially overlapped. The first, second, third and fourth resonant modes cover at least one identical first communication band, and the overall maximum array length of the four-antenna array along the first edge is between 0.25 wavelength and 0.49 wavelength of the lowest operating frequency of the first communication band.

DRAWINGS

FIG. **1**A is a structural diagram depicting a multi-antenna communication device **1** in accordance with an embodiment of the disclosure;

FIG. **1**B is a structural diagram depicting a four-antenna array **11** of the multi-antenna communication device **1** in accordance with an embodiment of the disclosure;

FIG. **1**C is a graph showing return loss of the four-antenna array **11** of the multi-antenna communication device **1** in accordance with an embodiment of the disclosure;

FIG. **1**D is a graph showing isolation level of the four-antenna array **11** of the multi-antenna communication device **1** in accordance with an embodiment of the disclosure;

FIG. 1E is a graph showing radiation efficiency of the four-antenna array 11 of the multi-antenna communication device 1 in accordance with an embodiment of the disclosure;

FIG. 1F is a graph showing envelope correlation coefficient of the four-antenna array of the multi-antenna communication device 1 in accordance with an embodiment of the disclosure;

FIG. 2A is a structural diagram depicting a multi-antenna communication device 2 in accordance with an embodiment of the disclosure;

FIG. 2B is a structural diagram depicting a four-antenna array 21 of the multi-antenna communication device 2 in accordance with an embodiment of the disclosure;

FIG. 2C is a graph showing return loss of the four-antenna array 21 of the multi-antenna communication device 2 in accordance with an embodiment of the disclosure;

FIG. 2D is a graph showing isolation level of the four-antenna array 21 of the multi-antenna communication device 2 in accordance with an embodiment of the disclosure;

FIG. 2E is a graph showing radiation efficiency of the four-antenna array 21 of the multi-antenna communication device 2 in accordance with an embodiment of the disclosure;

FIG. 2F is a graph showing envelope correlation coefficient of the four-antenna array 21 of the multi-antenna communication device 2 in accordance with an embodiment of the disclosure;

FIG. 3A is a structural diagram depicting a multi-antenna communication device 3 in accordance with an embodiment of the disclosure;

FIG. 3B is a structural diagram depicting a four-antenna array 31 of the multi-antenna communication device 3 in accordance with an embodiment of the disclosure;

FIG. 3C is a graph showing return loss of the four-antenna array 31 of the multi-antenna communication device in accordance with an embodiment of the disclosure;

FIG. 3D is a graph showing isolation level of the four-antenna array 31 of the multi-antenna communication device 3 in accordance with an embodiment of the disclosure;

FIG. 3E is a graph showing radiation efficiency of the four-antenna array 31 of the multi-antenna communication device 3 in accordance with an embodiment of the disclosure;

FIG. 3F is a graph showing envelope correlation coefficient of the four-antenna array 31 of the multi-antenna communication device 3 in accordance with an embodiment of the disclosure;

FIG. 4A is a structural diagram depicting a multi-antenna communication device 4 in accordance with an embodiment of the disclosure;

FIG. 4B is a structural diagram depicting a four-antenna array 41 of the multi-antenna communication device 4 in accordance with an embodiment of the disclosure;

FIG. 4C is a graph showing return loss of the four-antenna array 41 of the multi-antenna communication device 4 in accordance with an embodiment of the disclosure;

FIG. 4D is a graph showing isolation level of the four-antenna array 41 of the multi-antenna communication device 4 in accordance with an embodiment of the disclosure;

FIG. 4E is a graph showing radiation efficiency of the four-antenna array 41 of the multi-antenna communication device 4 in accordance with an embodiment of the disclosure;

FIG. 4F is a graph showing envelope correlation coefficient of the four-antenna array 41 of the multi-antenna communication device 4 in accordance with an embodiment of the disclosure;

FIG. 5A is a structural diagram depicting a multi-antenna communication device 5 in accordance with an embodiment of the disclosure;

FIG. 5B is a structural diagram depicting a four-antenna array 51 of the multi-antenna communication device 5 in accordance with an embodiment of the disclosure;

FIG. 6A is a structural diagram depicting a multi-antenna communication device 6 in accordance with an embodiment of the disclosure; and

FIG. 6B is a structural diagram depicting a four-antenna array 61 of the multi-antenna communication device 6 in accordance with an embodiment of the disclosure.

DETAILED DESCRIPTION

The disclosure provides embodiments of a multi-antenna communication device, which includes a grounding conductor plane and a four-antenna array. The grounding conductor plane separates a first side space and a second side space opposite to the first side space, and has a first edge. The four-antenna array is located at the first edge, and has an overall maximum array length extending along the first edge. In the four-antenna array, by providing four adjacent and downsized loop paths at the first edge, the grounding conductor plane could be effectively excited to create a more uniform strong current distribution, thus producing respective resonant modes. This effectively reduces the variation of input impedance of the four-antenna array with frequencies, and increases the respective operating bandwidths of the resonant modes. Moreover, the four-antenna array is configured with two loop paths in the first side space, and two loop paths in the second side space. The two adjacent and downsized loop paths in the first side space are able to effectively excite opposite current distributions along the first edge. The two adjacent and downsized loop paths in the second side space also able to effectively excite opposite current distributions along the first edge. As such, the envelope correlation coefficient between two adjacent downsized loop paths in the same side space could be effectively reduced, and the distance between the two adjacent downsized loop paths could thus be effectively reduced, resulting in a reduction in the maximum array length of the four-antenna array along the first edge. Furthermore, in the four-antenna array, by configuring projection line segments corresponding to two adjacent and downsized loop paths in different (the first and second) side spaces to be not completely overlapped with each other, the space wave energy coupling between adjacent downsized loop paths in the first side space and the second side space could be effectively reduced, resulting in a further reduction in the overall size of the four-antenna array and an improvement in the antenna radiation performance. The disclosure provides an integrated multi-antenna communication device with low correlation coefficient, which effectively reduces the overall size of the multi-antenna array applied in the communication device and satisfies the need for high speed/throughput data transmission in upcoming multi-antenna communication devices.

FIG. 1A is a structural diagram depicting a multi-antenna communication device 1 in accordance with an embodiment of the disclosure. FIG. 1B is a structural diagram depicting a four-antenna array 11 of the multi-antenna communication device 1 in accordance with an embodiment of the disclosure. FIG. 1C is a graph showing return loss of the four-antenna array 11 of the multi-antenna communication device 1 in accordance with an embodiment of the disclosure. The multi-antenna communication device 1 includes a grounding conductor plane 10 and a four-antenna array 11. The grounding conductor plane 10 separates a first side space 101 and a second side space 102 opposite to the first side space 101, and has a first edge 103. The four-antenna array 11 is located at the first edge 103, and has an overall maximum array length d extending along the first edge 103. As shown in FIGS. 1A and 1B, the four-antenna array 11 includes a first antenna 111, a second antenna 112, a third antenna 113 and a fourth antenna 114. As shown in FIG. 1B, the first antenna 111 is located in the first side space 101, and includes a first feeding conductor line 1112, a first grounding conductor line 1113, and a first radiating conductor portion 1111 electrically connected with a first signal source 1114 via the first feeding conductor line 1112 and electrically connected with the first edge 103 via the first grounding conductor line 1113, thereby forming a first loop path 1115 and generating at least one first resonant mode 1118 (as shown in FIG. 1C). The first radiating conductor portion 1111 has a first projection line segment 1116 at the first edge 103. The first loop path 1115 begins at the first signal source 1114, passes through the first feeding conductor line 1112, the first radiating conductor portion 1111, the first grounding conductor line 1113 and the first edge 103, and returns to the first signal source 1114. The second antenna 112 is located in the first side space 101, and includes a second feeding conductor line 1122, a second grounding conductor line 1123, and a second radiating conductor portion 1121 electrically connected with a second signal source 1124 via the second feeding conductor line 1122 and electrically connected with the first edge 103 via the second grounding conductor line 1123, thereby forming a second loop path 1125 and generating at least one second resonant mode 1128 (as shown in FIG. 1C). The second radiating conductor portion 1121 has a second projection line segment 1126 at the first edge 103. The second loop path 1125 begins at the second signal source 1124, passes through the second feeding conductor line 1122, the second radiating conductor portion 1121, the second grounding conductor line 1123 and the first edge 103, and returns to the second signal source 1124. The third antenna 113 is located in the second side space 102, and includes a third feeding conductor line 1132, a third grounding conductor line 1133, and a third radiating conductor portion 1131 electrically connected with a third signal source 1134 via the third feeding conductor line 1132 and electrically connected with the first edge 103 via the third grounding conductor line 1133, thereby forming a third loop path 1135 and generating at least one third resonant mode 1138 (as shown in FIG. 1C). The third radiating conductor portion 1131 has a third projection line segment 1136 at the first edge 103. The third loop path 1135 begins at the third signal source 1134, passes through the third feeding conductor line 1132, the third radiating conductor portion 1131, the third grounding conductor line 1133 and the first edge 103, and returns to the third signal source 1134. The fourth antenna 114 is located in the second side space 102, and includes a fourth feeding conductor line 1142, a fourth grounding conductor line 1143, and a fourth radiating conductor portion 1141 electrically connected with a fourth signal source 1144 via the fourth feeding conductor line 1142 and electrically connected with the first edge 103 via the fourth grounding conductor line 1143, thereby forming a fourth loop path 1145 and generating at least one fourth resonant mode 1148 (as shown in FIG. 1C). The fourth radiating conductor portion 1141 has a fourth projection line segment 1146 at the first edge 103. The fourth loop path 1145 begins at the fourth signal source 1144, passes through the fourth feeding conductor line 1142, the fourth radiating conductor portion 1141, the fourth grounding conductor line 1143 and the first edge 103, and returns to the fourth signal source 1144. The first projection line segment 1116 and the third projection line segment 1136 are partially but not completely overlapped. The second projection line segment 1126 and the fourth projection line segment 1146 are partially but not completely overlapped. The first, second, third, and fourth resonant modes 1118, 1128, 1138 and 1148 cover at least one identical first communication band 12 (as shown in FIG. 1C), and the overall maximum array length d of the four-antenna array 11 along the first edge 103 is between 0.25 wavelength and 0.49 wavelength of the lowest operating frequency of the first communication band 12. The lengths of the first loop path 1115, the second loop path 1125, the third loop path 1135 and the fourth loop path 1145 are all between 0.1 wavelength and 0.369 wavelength of the lowest operating frequency of the first communication band 12. The first feeding conductor line 1112 is spaced from the first radiating conductor portion 1111 at a first coupling gap 1117 that has an interval d1 less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band 12. The first grounding conductor line 1113 is electrically connected to the first radiating conductor portion 1111. With the first coupling gap 1117, a capacitive reactance could be created that effectively compensates the inductance of the first loop path 1115, thereby successfully reducing the length of the first loop path 1115. The second feeding conductor line 1122 is spaced from the second radiating conductor portion 1121 at a second coupling gap 1127 that has an interval d2 is less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band 12. The second grounding conductor line 1123 is electrically connected to the second radiating conductor portion 1121. With the second coupling gap 1127, a capacitive reactance could be created that effectively compensates the inductance of the second loop path 1125, thereby successfully reducing the length of the second loop path 1125. The third feeding conductor line 1132 is spaced from the third radiating conductor portion 1131 at a third coupling gap 1137 that has an interval d3 less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band 12. The third grounding conductor line 1133 is electrically connected to the third radiating conductor portion 1131. With the third coupling gap 1137, a capacitive reactance could be created that effectively compensates the inductance of the third loop path 1135, thereby successfully reducing the length of the third loop path 1135. The fourth feeding conductor line 1142 is spaced from the fourth radiating conductor portion 1141 at a fourth coupling gap 1147 that has an interval d4 less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band 12. The fourth grounding conductor line 1143 is electrically connected to the fourth radiating conductor portion 1141. With the fourth coupling gap 1147, a capacitive reactance could be created that effectively compensates the inductance of the fourth loop path 1145, thereby successfully reducing the length of the fourth loop path 1145. The lengths of the first radiating conductor portion 1111, the second radiating conductor portion 1121, the third radiating conductor portion 1131 and the fourth radiating conductor portion 1141 are all between 0.05 wavelength and 0.233 wavelength of the lowest operating frequency of the first communication band 12 (as shown in FIG. 1C). The lengths of the first projection line segment **1116**, the second projection line segment **1126**, the third projection line segment **1136** and the fourth projection line segment **1146** are all between 0.01 wavelength and 0.22 wavelength of the lowest operating frequency of the first communication band **12** (as shown in FIG. **1**C). Each of the first signal source **1114**, the second signal source **1124**, the third signal source **1134** and the fourth signal source **1144** could be a radio frequency circuit module, a radio frequency integrated circuit die, a radio frequency circuit switch, a radio frequency filter circuit, a radio frequency duplexer circuit, a radio frequency transmission line circuit, or a radio frequency capacitance, inductance or resistance matching circuit.

In the four-antenna array **11** of the multi-antenna communication device **1**, by providing four adjacent and downsized first loop path **1115**, second loop path **1125**, third loop path **1135** and fourth loop path **1145** at the first edge **103**, the grounding conductor plane **10** is effectively excited to create a more uniform strong current distribution, thus respectively producing the first resonant mode **1118**, the second resonant mode **1128**, the third resonant mode **1138** and the fourth resonant mode **1148**. This effectively reduces the variation of input impedance of the four-antenna array **11** with frequencies, and increases the respective operating bandwidths of the first resonant mode **1118**, the second resonant mode **1128**, the third resonant mode **1138** and the fourth resonant mode **1148**. Moreover, as the four-antenna array **11** is configured with the first loop path **1115** and the second loop path **1125** in the first side space **101**, and the third loop path **1135** and the fourth loop path **1145** in the second side space **102**, the first loop path **1115** and the second loop path **1125** in the first side space **101** are able to effectively excite opposite current distributions along the first edge **103**, and the third loop path **1135** and the fourth loop path **1145** in the second side space **102** are also able to effectively excite opposite current distributions along the first edge **103**. As such, the envelope correlation coefficient between two adjacent downsized loop paths in the same side space may be effectively reduced, and the distance between the two adjacent downsized loop paths may be effectively reduced, resulting in a reduction in the maximum array length d of the four-antenna array **11** along the first edge **103**. Furthermore, by allowing the first projection line segment **1116** and the third projection line segment **1136** to be partially but not completely overlapped, and the second projection line segment **1126** and the fourth projection line segment **1146** to be partially but not completely overlapped, the space wave energy coupling between adjacent downsized loop paths in the first side space **101** and the second side space **102** may be effectively reduced, resulting in a further reduction in the overall size of the four-antenna array **11** and an improvement in the antenna radiation characteristic.

FIG. **1**C is a graph showing return loss of the four-antenna array **11** of the multi-antenna communication device **1** in accordance with an embodiment of the disclosure. The following dimensions are used in the experiments: the four-antenna array **11** having a length of about 150 mm and a width of about 75 mm; the first edge **103** having a length of 150 mm; the first loop path **1115** having a length of about 26 mm, the second loop path **1125** having a length of about 27 mm, the third loop path **1135** having a length of about 25 mm, the fourth loop path **1145** having a length of about 26.5 mm; the maximum array length d of the four-antenna array **11** being about 36 mm; the first coupling gap **1117** having an interval d**1** of about 0.3 mm, the second coupling gap **1127** having an interval d**2** of about 0.5 mm, the third coupling gap **1137** having an interval d**3** of about 0.3 mm, the fourth coupling gap **1147** having an interval d**4** of about 0.35 mm; the first radiating conductor portion **1111** having a length of about 10 mm, the second radiating conductor portion **1121** having a length of about 10.5 mm, the third radiating conductor portion **1131** having a length of about 11 mm, the fourth radiating conductor portion **1141** having a length of about 10.5 mm; the maximum array length d of the four-antenna array **11** being about 36 mm; the first projection line segment **1116** having a length of about 10 mm, the second projection line segment **1126** having a length of about 10.5 mm, the third projection line segment **1136** having a length of about 11 mm, the fourth projection line segment **1146** having a length of about 10.5 mm. As shown in FIG. **1**C, the first loop path **1115** generates at least one first resonant mode **1118**, the second loop path **1125** generates at least one second resonant mode **1128**, the third loop path **1135** generates at least one third resonant mode **1138**, and the fourth loop path **1145** generates at least one fourth resonant mode **1148**. In an embodiment, the first resonant mode **1118**, the second resonant mode **1128**, the third resonant mode **1138** and the fourth resonant mode **1148** cover the identical first communication band **12** (3400 MHz-3600 MHz). The lowest operating frequency of the first communication band **12** is about 3400 MHz.

FIG. **1**D is a graph showing isolation level of the four-antenna array **11** of the multi-antenna communication device **1** in accordance with an embodiment of the disclosure. The isolation level between the first antenna **111** and the second antenna **112** is shown by a curve **1424**, the isolation level between the first antenna **111** and the third antenna **113** is shown by a curve **1434**, the isolation level between the first antenna **111** and the fourth antenna **114** is shown by a curve **1444**, and the isolation level between the second antenna **112** and the third antenna **113** is shown by a curve **2434**. As shown in FIG. **1**D, the curves of isolation level of the four-antenna array **11** in the first communication band **12** are all above 10 dB. FIG. **1**E is a graph showing radiation efficiency of the four-antenna array **11** of the multi-antenna communication device **1** in accordance with an embodiment of the disclosure. The radiation efficiency of the first antenna **111** is shown by a curve **1119**, the radiation efficiency of the second antenna **112** is shown by a curve **1129**, the radiation efficiency of the third antenna **113** is shown by a curve **1139**, and the radiation efficiency of the fourth antenna **114** is shown by a curve **1149**. As shown in FIG. **1**E, the radiation efficiency curves of the four-antenna array **11** in the first communication band **12** are all above 40%. FIG. **1**F is a graph showing envelope correlation coefficient of the four-antenna array **11** of the multi-antenna communication device **1** in accordance with an embodiment of the disclosure. The envelope correlation coefficient between the first antenna **111** and the second antenna **112** is shown by a curve **14241**, the envelope correlation coefficient between the first antenna **111** and the third antenna **113** is shown by a curve **14341**, the envelope correlation coefficient between the first antenna **111** and the fourth antenna **114** is shown by a curve **14441**, and the envelope correlation coefficient between the second antenna **112** and the third antenna **113** is shown by a curve **24341**. As shown in FIG. **1**F, the envelope correlation coefficient curves of the four-antenna array **11** in the first communication band **12** are all below 0.2.

The communication system operating band and experiment data described with respect to FIGS. **1**C, **1**D, **1**E and **1**F are merely to experimentally prove the technical effects of the multi-antenna communication device **1** according to the disclosure shown in FIGS. **1**A and **1**B, and do not intend to limit the communication operating bands, the applications and the specifications of the multi-antenna communication device of the disclosure in actual implementations. The multi-antenna communication device **1** according to the disclosure could be designed to cover system operating bands in WWAN (Wireless Wide Area Network), MIMO (Multi-input Multi-output) system, LTE (Long Term Evolution), pattern switchable antenna system, WLPN (Wireless Personal Network), WLAN (Wireless Local Area Network), beamforming antenna system, NFC (Near Field Communication), DTV (Digital Television Broadcasting System) or GPS (Global Positioning System). The four-antenna array **11** could be realized as a single set or multiple sets in the multi-antenna communication device **1** according to the disclosure. The multi-antenna communication device **1** could be a mobile communication device, a wireless communication device, a mobile computing device, a computer system, a telecommunication apparatus, a network apparatus or a computer or network peripheral.

FIG. **2**A is a structural diagram depicting a multi-antenna communication device **2** in accordance with an embodiment of the disclosure. FIG. **2**B is a structural diagram depicting a four-antenna array **21** of the multi-antenna communication device **2** in accordance with an embodiment of the disclosure. FIG. **2**C is a graph showing return loss of the four-antenna array **21** of the multi-antenna communication device **2** in accordance with an embodiment of the disclosure. As shown in FIG. **2**A, the multi-antenna communication device **2** includes a grounding conductor plane **20** and a four-antenna array **21**. The grounding conductor plane **20** separates a first side space **201** and a second side space **202** opposite to the first side space **201**, and has a first edge **203**. The four-antenna array **21** is located in the first edge **203**, and has an overall maximum array length d extending along the first edge **203**. As shown in FIGS. **2**A and **2**B, the four-antenna array **21** includes a first antenna **211**, a second antenna **212**, a third antenna **213** and a fourth antenna **214**. As shown in FIG. **2**B, the first antenna **211** is located in the first side space **201**, and includes a first feeding conductor line **2112**, a first grounding conductor line **2113**, and a first radiating conductor portion **2111** electrically connected with a first signal source **2114** via the first feeding conductor line **2112** and electrically connected with the first edge **203** via the first grounding conductor line **2113**, thereby forming a first loop path **2115** and generating at least one first resonant mode **2118** (as shown in FIG. **2**C). The first radiating conductor portion **2111** has a first projection line segment **2116** at the first edge **203**. The first loop path **2115** begins at the first signal source **2114**, passes through the first feeding conductor line **2112**, the first radiating conductor portion **2111**, the first grounding conductor line **2113** and the first edge **203**, and returns to the first signal source **2114**. The second antenna **212** is located in the first side space **201**, and includes a second feeding conductor line **2122**, a second grounding conductor line **2123**, and a second radiating conductor portion **2121** electrically connected with a second signal source **2124** via the second feeding conductor line **2122** and electrically connected with the first edge **203** via the second grounding conductor line **2123**, thereby forming a second loop path **2125** and generating at least one second resonant mode **2128** (as shown in FIG. **2**C). The second radiating conductor portion **2121** has a second projection line segment **2126** at the first edge **203**. The second loop path **2125** begins at the second signal source **2124**, passes through the second feeding conductor line **2122**, the second radiating conductor portion **2121**, the second grounding conductor line **2123** and the first edge **203**, and returns to the second signal source **2124**. The third antenna **213** is located in the second side space **202**, and includes a third feeding conductor line **2132**, a third grounding conductor line **2133**, and a third radiating conductor portion **2131** electrically connected with a third signal source **2134** via the third feeding conductor line **2132** and electrically connected with the first edge **203** via the third grounding conductor line **2133**, thereby forming a third loop path **2135** and generating at least one third resonant mode **2138** (as shown in FIG. **2**C). The third radiating conductor portion **2131** has a third projection line segment **2136** at the first edge **203**. The third loop path **2135** begins at the third signal source **2134**, passes through the third feeding conductor line **2132**, the third radiating conductor portion **2131**, the third grounding conductor line **2133** and the first edge **203**, and returns to the third signal source **2134**. The fourth antenna **214** is located in the second side space **202**, and includes a fourth feeding conductor line **2142**, a fourth grounding conductor line **2143**, and a fourth radiating conductor portion **2141** electrically connected with a fourth signal source **2144** via the fourth feeding conductor line **2142** and electrically connected with the first edge **203** via the fourth grounding conductor line **2143**, thereby forming a fourth loop path **2145** and generating at least one fourth resonant mode **2148** (as shown in FIG. **2**C). The fourth radiating conductor portion **2141** has a fourth projection line segment **2146** at the first edge **203**. The fourth loop path **2145** begins at the fourth signal source **2144**, passes through the fourth feeding conductor line **2142**, the fourth radiating conductor portion **2141**, the fourth grounding conductor line **2143** and the first edge **203**, and returns to the fourth signal source **2144**. The first projection line segment **2116** and the third projection line segment **2136** are partially but not completely overlapped. The second projection line segment **2126** and the fourth projection line segment **2146** are partially but not completely overlapped. The first, second, third, and fourth resonant modes **2118**, **2128**, **2138** and **2148** cover at least one identical first communication band **12** (as shown in FIG. **2**C), and the overall maximum array length d of the four-antenna array **21** along the first edge **203** is between 0.25 wavelength and 0.49 wavelength of the lowest operating frequency of the first communication band **12**. The lengths of the first loop path **2115**, the second loop path **2125**, the third loop path **2135** and the fourth loop path **2145** are all between 0.1 wavelength and 0.369 wavelength of the lowest operating frequency of the first communication band **12**. The first feeding conductor line **2112** is spaced from the first radiating conductor portion **2111** at a first coupling gap **2117** that has an interval d**1** less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band **12**. The first grounding conductor line **2113** is electrically connected to the first radiating conductor portion **2111**. With the first coupling gap **2117**, a capacitive reactance could be created that effectively compensates the inductance of the first loop path **2115**, thereby successfully reducing the required length of the first loop path **2115**. The second feeding conductor line **2122** and the second grounding conductor line **2123** are electrically connected to the second radiating conductor portion **2121**. The third feeding conductor line **2132** and the third grounding conductor line **2133** are electrically connected to the third radiating conductor portion **2131**. The fourth feeding conductor line **2142** is spaced from the fourth radiating conductor portion **2141** at a fourth coupling gap **2147** that has an interval d**4** less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band **12** (shown in FIG. **2**C). The fourth grounding conductor line **2143** is electrically connected to the fourth radiating conductor portion **2141**. With the fourth coupling gap **2147**, a capacitive reactance could be created that effectively compensates the inductance of the fourth loop path **2145**, thereby successfully reducing the required length of the fourth loop path **2145**. The lengths of the first radiating conductor portion **2111**, the second radiating conductor portion **2121**, the third radiating conductor portion **2131** and the fourth radiating conductor portion **2141** are all between 0.05 wavelength and 0.233 wavelength of the lowest operating frequency of the first communication band **12** (as shown in FIG. **2**C). The lengths of the first projection line segment **2116**, the second projection line segment **2126**, the third projection line segment **2136** and the fourth projection line segment **2146** are all between 0.01 wavelength and 0.22 wavelength of the lowest operating frequency of the first communication band **12** (as shown in FIG. **2**C). Each of the first signal source **2114**, the second signal source **2124**, the third signal source **2134** and the fourth signal source **2144** could be a radio frequency circuit module, a radio frequency integrated circuit, a radio frequency circuit switch, a radio frequency filter circuit, a radio frequency duplexer circuit, a radio frequency transmission line circuit, or a radio frequency capacitance, inductance or resistance matching circuit.

In the four-antenna array **21** of the multi-antenna communication device **2**, although the second radiating conductor portion **2121** is shaped different from the second radiating conductor portion **1121** in the multi-antenna communication device **1**, the second feeding conductor line **2122** is electrically connected with the second radiating conductor portion **2121**, the third radiating conductor portion **2131** is shaped different from the third radiating conductor portion **1131** in the multi-antenna communication device **1**, and the third feeding conductor line **2132** is electrically connected with the third radiating conductor portion **2131**, when the second signal source **2124** and the third signal source **2134** are radio frequency capacitance matching circuits, capacitive reactance can also be generated, which effectively compensate the inductances of the second loop path **2125** and the third loop path **2135**, thereby successfully reducing the lengths of the second loop path **2125** and the third loop path **2135**. Therefore, by providing four adjacent and downsized first loop path **2115**, second loop path **2125**, third loop path **2135** and fourth loop path **2145** at the first edge **203**, the multi-antenna communication device **2** can effectively excite the grounding conductor plane **20** to create a more uniform strong current distribution, thus respectively producing the first resonant mode **2118**, the second resonant mode **2128**, the third resonant mode **2138** and the fourth resonant mode **2148**. This also effectively reduces the variation of input impedance of the four-antenna array **21** with the frequencies, and increases the respective operating bandwidths of the first resonant mode **2118**, the second resonant mode **2128**, the third resonant mode **2138** and the fourth resonant mode **2148**. Moreover, as the four-antenna array **21** is configured with the first loop path **2115** and the second loop path **2125** at the first side space **201**, and the third loop path **2135** and the fourth loop path **2145** at the second side space **202**, the first loop path **2115** and the second loop path **2125** at the first side space **201** are able to effectively excite opposite current distributions along the first edge **203**, and the third loop path **2135** and the fourth loop path **2145** at the second side space **202** are also able to effectively excite opposite current distributions along the first edge **203**. As such, the envelope correlation coefficient between two adjacent downsized loop paths at the same side space could be effectively reduced, and the distance between the two adjacent downsized loop paths could be effectively reduced, resulting in a reduction in the maximum array length d of the four-antenna array **21** along the first edge **203**. Furthermore, by allowing the first projection line segment **2116** and the third projection line segment **2136** to partially but not completely overlap, and the second projection line segment **2126** and the fourth projection line segment **2146** to partially but not completely overlap, the space wave energy coupling between adjacent downsized loop paths at the first side space **201** and the second side space **202** could be effectively reduced, resulting in a further reduction in the overall size of the four-antenna array **21** and an improvement in the antenna radiation characteristic. Thus, the multi-antenna communication device **2** achieves similar technical effect/performance provided by the multi-antenna communication device **1**.

FIG. **2**C is a graph showing return loss of the four-antenna array **21** of the multi-antenna communication device **2** in accordance with an embodiment of the disclosure. The following dimensions are used in the experiments: the first edge **203** having a length of 160 mm; the first loop path **2115** having a length of about 26 mm, the second loop path **2125** having a length of about 18 mm, the third loop path **2135** having a length of about 17.5 mm, the fourth loop path **2145** having a length of about 26 mm; the maximum array length d of the four-antenna array **21** being about 40 mm; the first coupling gap **2117** having an interval d**1** of about 0.3 mm, the fourth coupling gap **2147** having an interval d**4** of about 0.3 mm; the first radiating conductor portion **2111** having a length of about 11 mm, the second radiating conductor portion **2121** having a length of about 16 mm, the third radiating conductor portion **2131** having a length of about 17 mm, the fourth radiating conductor portion **2141** having a length of about 10.5 mm; the maximum array length d of the four-antenna array **21** being about 36 mm; the first projection line segment **2116** having a length of about 11 mm, the second projection line segment **2126** having a length of about 16 mm, the third projection line segment **2136** having a length of about 17 mm, the fourth projection line segment **2146** having a length of about 10.5 mm. As shown in FIG. **2**C, the first loop path **2115** generates at least one first resonant mode **2118**, the second loop path **2125** generates at least one second resonant mode **2128**, the third loop path **2135** generates at least one third resonant mode **2138**, and the fourth loop path **2145** generates at least one fourth resonant mode **2148**. In this embodiment, the first resonant mode **2118**, the second resonant mode **2128**, the third resonant mode **2138** and the fourth resonant mode **2148** cover the identical first communication band **12** (3400 MHz-3600 MHz). The lowest operating frequency of the first communication band **12** is about 3400 MHz.

FIG. **2**D is a graph showing the isolation level of the four-antenna array **21** of the multi-antenna communication device **2** in accordance with an embodiment of the disclosure. The isolation level between the first antenna **211** and the second antenna **212** is shown by a curve **1424**, the isolation level between the first antenna **211** and the third antenna **213** is shown by a curve **1434**, the isolation level between the first antenna **211** and the fourth antenna **214** is shown by a curve **1444**, the isolation level between the second antenna **212** and the third antenna **213** is shown by a curve **2434**. As shown in FIG. **2**D, the curves of isolation level of the four-antenna array **21** in the first communication band **12** are all above 10 dB. FIG. **2**E is a graph showing radiation efficiency of the four-antenna array **21** of the multi-antenna communication device **2** in accordance with an embodiment of the disclosure. The radiation efficiency of the first antenna **211** is shown by a curve **2119**, the radiation efficiency of the second antenna **212** is shown by a curve **2129**, the radiation efficiency of the third antenna **213** is shown by a curve **2139**, and the radiation efficiency of the fourth antenna **214** is shown by a curve **2149**. As shown in FIG. **2**E, the radiation efficiency curves of the four-antenna array **21** in the first communication band **12** are all above 40%. FIG. **2**F is a graph showing envelope correlation coefficient of the four-antenna array **21** of the multi-antenna communication device **2** in accordance with an embodiment of the disclosure. The envelope correlation coefficient between the first antenna **211** and the second antenna **212** is shown by a curve **14241**, the envelope correlation coefficient between the first antenna **211** and the third antenna **213** is shown by a curve **14341**, the envelope correlation coefficient between the first antenna **211** and the fourth antenna **214** is shown by a curve **14441**, and the envelope correlation coefficient between the second antenna **212** and the third antenna **213** is shown by a curve **24341**. As shown in FIG. **2**F, the envelope correlation coefficient curves of the four-antenna array **11** in the first communication band **12** are all below 0.2.

The communication system operating band and experiment data described with respect to FIGS. **2**C, **2**D, **2**E and **2**F are merely to experimentally prove the technical effects of the multi-antenna communication device **2** according to the disclosure shown in FIGS. **2**A and **2**B, and do not intend to limit the communication operating bands, the applications and the specifications of the multi-antenna communication device of the disclosure in actual implementations. The multi-antenna communication device **2** according to the disclosure may be designed to cover system operating bands in WWAN (Wireless Wide Area Network), MIMO (Multi-input Multi-output) system, LTE (Long Term Evolution), pattern switchable antenna system, WLPN (Wireless Personal Network), WLAN (Wireless Local Area Network), beamforming antenna system, NFC (Near Field Communication), DTV (Digital Television Broadcasting System) or GPS (Global Positioning System). The four-antenna array **21** could be realized as a single set or multiple sets in the multi-antenna communication device **2** of the disclosure. The multi-antenna communication device **2** could be a mobile communication device, a wireless communication device, a mobile computing device, a computer system, a telecommunication apparatus, a network apparatus or a computer or network peripheral.

FIG. **3**A is a structural diagram depicting a multi-antenna communication device **3** in accordance with an embodiment of the disclosure. FIG. **3**B is a structural diagram depicting a four-antenna array **31** of the multi-antenna communication device **3** in accordance with an embodiment of the disclosure. FIG. **3**C is a graph showing return loss of the four-antenna array **31** of the multi-antenna communication device **3** in accordance with an embodiment of the disclosure. As shown in FIG. **3**A, the multi-antenna communication device **3** includes a grounding conductor plane **30** and a four-antenna array **31**. The grounding conductor plane **30** separates a first side space **301** and a second side space **302** opposite to the first side space **301**, and has a first edge **303**. The four-antenna array **31** is located at the first edge **303**, and has an overall maximum array length d extending along the first edge **303**. As shown in FIGS. **3**A and **3**B, the four-antenna array **31** includes a first antenna **311**, a second antenna **312**, a third antenna **313** and a fourth antenna **314**. As shown in FIG. **3**B, the first antenna **311** is located in the first side space **301**, and includes a first feeding conductor line **3112**, a first grounding conductor line **3113**, and a first radiating conductor portion **3111** electrically connected with a first signal source **3114** via the first feeding conductor line **3112** and electrically connected with the first edge **303** via the first grounding conductor line **3113**, thereby forming a first loop path **3115** and generating at least one first resonant mode **3118** (as shown in FIG. **3**C). The first radiating conductor portion **3111** has a first projection line segment **3116** at the first edge **303**. The first loop path **3115** begins at the first signal source **3114**, passes through the first feeding conductor line **3112**, the first radiating conductor portion **3111**, the first grounding conductor line **3113** and the first edge **303**, and returns to the first signal source **3114**. The second antenna **312** is located in the first side space **301**, and includes a second feeding conductor line **3122**, a second grounding conductor line **3123**, and a second radiating conductor portion **3121** electrically connected with a second signal source **3124** via the second feeding conductor line **3122** and electrically connected with the first edge **303** via the second grounding conductor line **3123**, thereby forming a second loop path **3125** and generating at least one second resonant mode **3128** (as shown in FIG. **3**C). The second radiating conductor portion **3121** has a second projection line segment **3126** at the first edge **303**. The second loop path **3125** begins at the second signal source **3124**, passes through the second feeding conductor line **3122**, the second radiating conductor portion **3121**, the second grounding conductor line **3123** and the first edge **303**, and returns to the second signal source **3124**. The third antenna **313** is located in the second side space **302**, and includes a third feeding conductor line **3132**, a third grounding conductor line **3133**, and a third radiating conductor portion **3131** electrically connected with a third signal source **3134** via the third feeding conductor line **3132** and electrically connected with the first edge **303** via the third grounding conductor line **3133**, thereby forming a third loop path **3135** and generating at least one third resonant mode **3138** (as shown in FIG. **3**C). The third radiating conductor portion **3131** has a third projection line segment **3136** at the first edge **303**. The third loop path **3135** beings at the third signal source **3134**, passes through the third feeding conductor line **3132**, the third radiating conductor portion **3131**, the third grounding conductor line **3133** and the first edge **303**, and returns to the third signal source **3134**. The fourth antenna **314** is located in the second side space **302**, and includes a fourth feeding conductor line **3142**, a fourth grounding conductor line **3143**, and a fourth radiating conductor portion **3141** electrically connected with a fourth signal source **3144** via the fourth feeding conductor line **3142** and electrically connected with the first edge **303** via the fourth grounding conductor line **3143**, thereby forming a fourth loop path **3145** and generating at least one fourth resonant mode **3148** (as shown in FIG. **3**C). The fourth radiating conductor portion **3141** has a fourth projection line segment **3146** at the first edge **303**. The fourth loop path **3145** begins at the fourth signal source **3144**, passes through the fourth feeding conductor line **3142**, the fourth radiating conductor portion **3141**, the fourth grounding conductor line **3143** and the first edge **303**, and returns to the fourth signal source **3144**. The first projection line segment **3116** and the third projection line segment **3136** are partially but not completely overlapped. The second projection line segment **3126** and the fourth projection line segment **3146** are partially but not completely overlapped. The first, second, third, and fourth resonant modes **3118**, **3128**, **3138** and **3148** cover at least one identical first communication band **12** (as shown in FIG. **3**C), and the overall maximum array length d of the four-antenna array **31** along the first edge **303** is between 0.25 wavelength and 0.49 wavelength of the lowest operating frequency of the first communication band **12**. The lengths of the first loop path **3115**, the second loop path **3125**, the third loop path **3135** and the fourth loop path **3145** are all between 0.1 wavelength and 0.369 wavelength of the lowest operating frequency of the first communication band **12**. The first feeding conductor line **3112** and the first grounding conductor line **3113** are electrically connected to the first radiating conductor portion **3111**. The second feeding conductor line **3122** is spaced from the second radiating conductor portion **3121** at a second coupling gap **3127** that has an interval d**2** less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band **12** (shown in FIG. **3**C). The second grounding conductor line **3123** is electrically connected to the second radiating conductor portion **3121**. With the second coupling gap **3127**, a capacitive reactance could be created that effectively compensates the inductance of the second loop path **3125**, thereby successfully reducing the required length of the second loop path **3125**. The third feeding conductor line **3132** is spaced from the third radiating conductor portion **3131** at a third coupling gap **3137** that has an interval d**3** less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band **12** (shown in FIG. **3**C). The third grounding conductor line **3133** is electrically connected to the third radiating conductor portion **3131**. With the third coupling gap **3137**, a capacitive reactance could be created that effectively compensates the inductance of the third loop path **3135**, thereby successfully reducing the required length of the third loop path **3135**. The fourth feeding conductor line **3142** and the fourth grounding conductor line **3143** are electrically connected to the fourth radiating conductor portion **3141**. The lengths of the first radiating conductor portion **3111**, the second radiating conductor portion **3121**, the third radiating conductor portion **3131** and the fourth radiating conductor portion **3141** are all between 0.05 wavelength and 0.233 wavelength of the lowest operating frequency of the first communication band **12** (as shown in FIG. **3**C). The lengths of the first projection line segment **3116**, the second projection line segment **3126**, the third projection line segment **3136** and the fourth projection line segment **3146** are all between 0.01 wavelength and 0.22 wavelength of the lowest operating frequency of the first communication band **12** (as shown in FIG. **3**C). Each of the first signal source **3114**, the second signal source **3124**, the third signal source **3134** and the fourth signal source **3144** could be a radio frequency circuit module, a radio frequency integrated circuit die, a radio frequency circuit switch, a radio frequency filter circuit, a radio frequency duplexer circuit, a radio frequency transmission line circuit, or a radio frequency capacitance, inductance or resistance matching circuit.

In the four-antenna array **31** of the multi-antenna communication device **3**, although the first feeding conductor line **3112** is electrically connected with the first radiating conductor portion **3111**, and the fourth feeding conductor line **3142** is electrically connected with the fourth radiating conductor portion **3141**, which are slightly different from the multi-antenna communication device **1**, when the first signal source **3114** and the fourth signal source **3144** are radio frequency capacitance matching circuits, capacitive reactance can also be generated, which effectively compensate the inductances of the first loop path **3115** and the fourth loop path **3145**, thereby successfully reducing the required lengths of the first loop path **3115** and the fourth loop path **3145**. Therefore, by providing four adjacent and downsized first loop path **3115**, second loop path **3125**, third loop path **3135** and fourth loop path **3145** at the first edge **303**, the multi-antenna communication device **3** can effectively excite the grounding conductor plane **30** to create a more uniform strong current distribution, thus respectively producing the first resonant mode **3118**, the second resonant mode **3128**, the third resonant mode **3138** and the fourth resonant mode **3148** (shown in FIG. **3**C). This also effectively reduces the variation of input impedance of the four-antenna array **31** with frequencies, and increases the respective operating bandwidths of the first resonant mode **3118**, the second resonant mode **3128**, the third resonant mode **3138** and the fourth resonant mode **3148**. Moreover, as the four-antenna array **31** is configured with the first loop path **3115** and the second loop path **3125** in the first side space **301**, and the third loop path **3135** and the fourth loop path **3145** in the second side space **302**, the first loop path **3115** and the second loop path **3125** at the first side space **301** are able to effectively excite opposite current distributions along the first edge **303**, and the third loop path **3135** and the fourth loop path **3145** in the second side space **302** are also able to effectively excite opposite current distributions along the first edge **303**. As such, the envelope correlation coefficient between two adjacent downsized loop paths in the same side space could be effectively reduced, and the distance between the two adjacent downsized loop paths could be effectively reduced, resulting in a reduction in the maximum array length d of the four-antenna array **31** along the first edge **303**. Furthermore, by allowing the first projection line segment **3116** and the third projection line segment **3136** to be partially but not completely overlapped, and the second projection line segment **3126** and the fourth projection line segment **3146** to be partially but not completely overlapped, the space wave energy coupling between adjacent downsized loop paths at the first side space **301** and the second side space **302** could be effectively reduced, resulting in a further reduction in the overall size of the four-antenna array **31** and an improvement in the antenna radiation characteristic. Thus, the multi-antenna communication device **3** achieves similar technical effect provided by the multi-antenna communication device **1**.

FIG. **3**C is a graph showing return loss of the four-antenna array **31** of the multi-antenna communication device **3** in accordance with an embodiment of the disclosure. The following dimensions are used in the experiments: the first edge **303** having a length of 180 mm; the first loop path **3115** having a length of about 26 mm, the second loop path **3125** having a length of about 27 mm, the third loop path **3135** having a length of about 25 mm, the fourth loop path **3145** having a length of about 26.5 mm; the maximum array length d of the four-antenna array **31** being about 36 mm; the second coupling gap **3127** having an interval d**2** of about 0.5 mm, the third coupling gap **3137** having an interval d**3** of about 0.3 mm; the first radiating conductor portion **3111** having a length of about 10 mm, the second radiating conductor portion **3121** having a length of about 10.5 mm, the third radiating conductor portion **3131** having a length of about 11 mm, the fourth radiating conductor portion **3141** having a length of about 10.5 mm; the maximum array length d of the four-antenna array **31** being about 36 mm; the first projection line segment **3116** having a length of about 10 mm, the second projection line segment **3126** having a length of about 10.5 mm, the third projection line segment **3136** having a length of about 11 mm, the fourth projection line segment **3146** having a length of about 10.5 mm. As shown in FIG. **3**C, the first loop path **3115** generates at least one first resonant mode **3118**, the second loop path **3125** generates at least one second resonant mode **3128**, the third loop path **3135** generates at least one third resonant mode

3138, and the fourth loop path 3145 generates at least one fourth resonant mode 3148. In this embodiment, the first resonant mode 3118, the second resonant mode 3128, the third resonant mode 3138 and the fourth resonant mode 3148 cover the identical first communication band 12 (3400 MHz-3600 MHz). The lowest operating frequency of the first communication band 12 is about 3400 MHz.

FIG. 3D is a graph showing the isolation level of the four-antenna array 31 of the multi-antenna communication device 3 in accordance with an embodiment of the disclosure. The isolation level between the first antenna 311 and the second antenna 312 is shown by a curve 1424, the isolation level between the first antenna 311 and the third antenna 313 is shown by a curve 1434, the isolation level between the first antenna 311 and the fourth antenna 314 is shown by a curve 1444, the isolation level between the second antenna 312 and the third antenna 313 is shown by a curve 2434. As shown in FIG. 3D, the curves of isolation level of the four-antenna array 31 in the first communication band 12 are all above 10 dB. FIG. 3E is a graph showing radiation efficiency of the four-antenna array 31 of the multi-antenna communication device 3 in accordance with an embodiment of the disclosure. The radiation efficiency of the first antenna 311 is shown by a curve 3119, the radiation efficiency of the second antenna 312 is shown by a curve 3129, the radiation efficiency of the third antenna 313 is shown by a curve 3139, and the radiation efficiency of the fourth antenna 314 is shown by a curve 3149. As shown in FIG. 3E, the radiation efficiency curves of the four-antenna array 31 in the first communication band 12 are all above 40%. FIG. 3F is a graph showing envelope correlation coefficient of the four-antenna array 31 of the multi-antenna communication device 3 in accordance with an embodiment of the disclosure. The envelope correlation coefficient between the first antenna 311 and the second antenna 312 is shown by a curve 14241, the envelope correlation coefficient between the first antenna 311 and the third antenna 313 is shown by a curve 14341, the envelope correlation coefficient between the first antenna 311 and the fourth antenna 314 is shown by a curve 14441, and the envelope correlation coefficient between the second antenna 312 and the third antenna 313 is shown by a curve 24341. As shown in FIG. 3F, the envelope correlation coefficient curves of the four-antenna array 31 in the first communication band 12 are all below 0.2.

The communication system operating band and experiment data described with respect to FIGS. 3C, 3D, 3E and 3F are merely to experimentally prove the technical effects of the multi-antenna communication device 3 according to the disclosure shown in FIGS. 3A and 3B, and do not intend to limit the communication operating bands, the applications and the specifications of the multi-antenna communication device of the disclosure in actual implementations. The multi-antenna communication device 3 according to the disclosure may be designed to cover system operating bands in WWAN (Wireless Wide Area Network), MIMO (Multi-input Multi-output) system, LTE (Long Term Evolution), pattern switchable antenna system, WLPN (Wireless Personal Network), WLAN (Wireless Local Area Network), beamforming antenna system, NFC (Near Field Communication), DTV (Digital Television Broadcasting System) or GPS (Global Positioning System). The four-antenna array 31 could be realized as a single set or multiple sets in the multi-antenna communication device 3 according to the disclosure. The multi-antenna communication device 3 could be a mobile communication device, a wireless communication device, a mobile computing device, a computer system, a telecommunication apparatus, a network apparatus or a computer or network peripheral.

FIG. 4A is a structural diagram depicting a multi-antenna communication device 4 in accordance with an embodiment of the disclosure. FIG. 4B is a structural diagram depicting a four-antenna array 41 of the multi-antenna communication device 4 in accordance with an embodiment of the disclosure. FIG. 4C is a graph showing return loss of the four-antenna array 41 of the multi-antenna communication device 4 in accordance with an embodiment of the disclosure. As shown in FIG. 4A, the multi-antenna communication device 4 includes a grounding conductor plane 40 and a four-antenna array 41. The grounding conductor plane 40 separates a first side space 401 and a second side space 402 opposite to the first side space 401, and has a first edge 403. The four-antenna array 41 is located at the first edge 403, and has an overall maximum array length d extending along the first edge 403. As shown in FIGS. 4A and 4B, the four-antenna array 41 includes a first antenna 411, a second antenna 412, a third antenna 413 and a fourth antenna 414. As shown in FIG. 4B, the first antenna 411 is located in the first side space 401, and includes a first feeding conductor line 4112, a first grounding conductor line 4113, and a first radiating conductor portion 4111 electrically connected with a first signal source 4114 via the first feeding conductor line 4112 and electrically connected with the first edge 403 via the first grounding conductor line 4113, thereby forming a first loop path 4115 and generating at least one first resonant mode 4118 (as shown in FIG. 4C). The first radiating conductor portion 4111 has a first projection line segment 4116 at the first edge 403. The first loop path 4115 begins at the first signal source 4114, passes through the first feeding conductor line 4112, the first radiating conductor portion 4111, the first grounding conductor line 4113 and the first edge 403, and returns to the first signal source 4114. The second antenna 412 is located in the first side space 401, and includes a second feeding conductor line 4122, a second grounding conductor line 4123, and a second radiating conductor portion 4121 electrically connected with a second signal source 4124 via the second feeding conductor line 4122 and electrically connected with the first edge 403 via the second grounding conductor line 4123, thereby forming a second loop path 4125 and generating at least one second resonant mode 4128 (as shown in FIG. 4C). The second radiating conductor portion 4121 has a second projection line segment 4126 at the first edge 403. The second loop path 4125 begins at the second signal source 4124, passes through the second feeding conductor line 4122, the second radiating conductor portion 4121, the second grounding conductor line 4123 and the first edge 403, and returns to the second signal source 4124. The third antenna 413 is located in the second side space 402, and includes a third feeding conductor line 4132, a third grounding conductor line 4133, and a third radiating conductor portion 4131 electrically connected with a third signal source 4134 via the third feeding conductor line 4132 and electrically connected with the first edge 403 via the third grounding conductor line 4133, thereby forming a third loop path 4135 and generating at least one third resonant mode 4138 (as shown in FIG. 4C). The third radiating conductor portion 4131 has a third projection line segment 4136 at the first edge 403. The third loop path 4135 begins at the third signal source 4134, passes through the third feeding conductor line 4132, the third radiating conductor portion 4131, the third grounding conductor line 4133 and the first edge 403, and returns to the third signal source 4134. The fourth antenna 414 is located in the second side space 402, and includes a fourth feeding conductor line **4142**, a fourth grounding conductor line **4143**, and a fourth radiating conductor portion **4141** electrically connected with a fourth signal source **4144** via the fourth feeding conductor line **4142** and electrically connected with the first edge **403** via the fourth grounding conductor line **4143**, thereby forming a fourth loop path **4145** and generating at least one fourth resonant mode **4148** (as shown in FIG. **4**C). The fourth radiating conductor portion **4141** has a fourth projection line segment **4146** at the first edge **403**. The fourth loop path **4145** begins at the fourth signal source **4144**, passes through the fourth feeding conductor line **4142**, the fourth radiating conductor portion **4141**, the fourth grounding conductor line **4143** and the first edge **403**, and returns to the fourth signal source **4144**. The first projection line segment **4116** and the third projection line segment **4136** are partially but not completely overlapped. The second projection line segment **4126** and the fourth projection line segment **4146** are partially but not completely overlapped. The first, second, third, and fourth resonant modes **4118**, **4128**, **4138** and **4148** cover at least one identical first communication band **12** (as shown in FIG. **4**C), and the overall maximum array length d of the four-antenna array **41** along the first edge **403** is between 0.25 wavelength and 0.49 wavelength of the lowest operating frequency of the first communication band **12**. The lengths of the first loop path **4115**, the second loop path **4125**, the third loop path **4135** and the fourth loop path **4145** are all between 0.1 wavelength and 0.369 wavelength of the lowest operating frequency of the first communication band **12**. The first feeding conductor line **4112** and the first grounding conductor line **4113** are electrically connected to the first radiating conductor portion **4111**. The second feeding conductor line **4122** and the second grounding conductor line **4123** are electrically connected to the second radiating conductor portion **4121**. The third feeding conductor line **4132** and the third grounding conductor line **4133** are electrically connected to the third radiating conductor portion **4131**. The fourth feeding conductor line **4142** and the fourth grounding conductor line **4143** are electrically connected to the fourth radiating conductor portion **4141**. The lengths of the first radiating conductor portion **4111**, the second radiating conductor portion **4121**, the third radiating conductor portion **4131** and the fourth radiating conductor portion **4141** are all between 0.05 wavelength and 0.233 wavelength of the lowest operating frequency of the first communication band **12** (as shown in FIG. **4**C). The lengths of the first projection line segment **4116**, the second projection line segment **4126**, the third projection line segment **4136** and the fourth projection line segment **4146** are all between 0.01 wavelength and 0.22 wavelength of the lowest operating frequency of the first communication band **12** (as shown in FIG. **4**C). Each of the first signal source **4114**, the second signal source **4124**, the third signal source **4134** and the fourth signal source **4144** could be a radio frequency circuit module, a radio frequency integrated circuit die, a radio frequency circuit switch, a radio frequency filter circuit, a radio frequency duplexer circuit, a radio frequency transmission line circuit, or a radio frequency capacitance, inductance or resistance matching circuit.

In the four-antenna array **41** of the multi-antenna communication device **4**, although the second feeding conductor line **4112** is electrically connected with the second radiating conductor portion **4121**, and the third feeding conductor line **4132** is electrically connected with the third radiating conductor portion **4131**, which are slightly different from the multi-antenna communication device **3**, when the second signal source **4124** and the third signal source **4134** are radio frequency capacitance matching circuits, capacitive reactance can also be generated, which effectively compensate the inductances of the second loop path **4125** and the third loop path **4135**, thereby successfully reducing the lengths of the second loop path **4125** and the third loop path **4135**. Therefore, by providing four adjacent and downsized first loop path **4115**, second loop path **4125**, third loop path **4135** and fourth loop path **4145** at the first edge **403**, the multi-antenna communication device **4** can effectively excite the grounding conductor plane **40** to create a more uniform strong current distribution, thus respectively producing the first resonant mode **4118**, the second resonant mode **4128**, the third resonant mode **4138** and the fourth resonant mode **4148** (shown in FIG. **4**C). This also effectively reduces the variation of input impedance of the four-antenna array **41** with the frequency, and increases the respective operating bandwidths of the first resonant mode **4118**, the second resonant mode **4128**, the third resonant mode **4138** and the fourth resonant mode **4148**. Moreover, as the four-antenna array **41** is configured with the first loop path **4115** and the second loop path **4125** in the first side space **401**, and the third loop path **4135** and the fourth loop path **4145** in the second side space **402**, the first loop path **4115** and the second loop path **4125** in the first side space **401** are able to effectively excite opposite current distributions along the first edge **403**, and the third loop path **4135** and the fourth loop path **4145** in the second side space **402** are also able to effectively excite opposite current distributions along the first edge **403**. As such, the envelope correlation coefficient between two adjacent downsized loop paths in the same side space may be effectively reduced, and the distance between the two adjacent downsized loop paths may be effectively reduced, resulting in a reduction in the maximum array length d of the four-antenna array **41** along the first edge **403**. Furthermore, by allowing the first projection line segment **4116** and the third projection line segment **4136** to be partially but not completely overlapped, and the second projection line segment **4126** and the fourth projection line segment **4146** to be partially but not completely overlapped, the space wave energy coupling between adjacent downsized loop paths in the first side space **401** and the second side space **402** may be effectively reduced, resulting in a further reduction in the overall size of the four-antenna array **41** and an improvement in the antenna radiation characteristic. Thus, the multi-antenna communication device **4** can achieve similar technical effect provided by the multi-antenna communication device **3**.

FIG. **4**C is a graph showing return loss of the four-antenna array **41** of the multi-antenna communication device **4** in accordance with an embodiment of the disclosure. The following dimensions are used in the experiments: the first edge **403** having a length of 160 mm; the first loop path **4115** having a length of about 26 mm, the second loop path **4125** having a length of about 27 mm, the third loop path **4135** having a length of about 25 mm, the fourth loop path **4145** having a length of about 26.5 mm; the maximum array length d of the four-antenna array **41** being about 36 mm; the first radiating conductor portion **4111** having a length of about 10 mm, the second radiating conductor portion **4121** having a length of about 10.5 mm, the third radiating conductor portion **4131** having a length of about 11 mm, the fourth radiating conductor portion **4141** having a length of about 10.5 mm; the maximum array length d of the four-antenna array **41** being about 36 mm; the first projection line segment **4116** having a length of about 10 mm, the second projection line segment **4126** having a length of about 10.5 mm, the third projection line segment **4136** having a length of about 11 mm, the fourth projection line segment **4146** having a length of about 10.5 mm. As shown in FIG. **4**C, the first loop path **4115** generates at least one first resonant mode **4118**, the second loop path **4125** generates at least one second resonant mode **4128**, the third loop path **4135** generates at least one third resonant mode **4138**, and the fourth loop path **4145** generates at least one fourth resonant mode **4148**. In this embodiment, the first resonant mode **4118**, the second resonant mode **4128**, the third resonant mode **4138** and the fourth resonant mode **4148** cover the identical first communication band **12** (3400 MHz-3600 MHz). The lowest operating frequency of the first communication band **12** is about 3400 MHz.

FIG. **4**D is a graph showing the isolation level of the four-antenna array **41** of the multi-antenna communication device **4** in accordance with an embodiment of the disclosure. The isolation level between the first antenna **411** and the second antenna **412** is shown by a curve **1424**, the isolation level between the first antenna **411** and the third antenna **413** is shown by a curve **1434**, the isolation level between the first antenna **411** and the fourth antenna **414** is shown by a curve **1444**, the isolation level between the second antenna **412** and the third antenna **413** is shown by a curve **2434**. As shown in FIG. **4**D, the curves of isolation level of the four-antenna array **41** in the first communication band **12** are all above 10 dB. FIG. **4**E is a graph showing radiation efficiency of the four-antenna array **41** of the multi-antenna communication device **4** in accordance with an embodiment of the disclosure. The radiation efficiency of the first antenna **411** is shown by a curve **4119**, the radiation efficiency of the second antenna **412** is shown by a curve **4129**, the radiation efficiency of the third antenna **413** is shown by a curve **4139**, and the radiation efficiency of the fourth antenna **414** is shown by a curve **4149**. As shown in FIG. **4**E, the radiation efficiency curves of the four-antenna array **41** in the first communication band **12** are all above 40%. FIG. **4**F is a graph showing envelope correlation coefficient of the four-antenna array **41** of the multi-antenna communication device **4** in accordance with an embodiment of the disclosure. The envelope correlation coefficient between the first antenna **411** and the second antenna **412** is shown by a curve **14241**, the envelope correlation coefficient between the first antenna **411** and the third antenna **413** is shown by a curve **14341**, the envelope correlation coefficient between the first antenna **411** and the fourth antenna **414** is shown by a curve **14441**, and the envelope correlation coefficient between the second antenna **412** and the third antenna **413** is shown by a curve **24341**. As shown in FIG. **4**F, the envelope correlation coefficient curves of the four-antenna array **41** in the first communication band **12** are all below 0.2.

The communication system operating band and experiment data described with respect to FIGS. **4**C, **4**D, **4**E and **4**F are merely to experimentally prove the technical effects of the multi-antenna communication device **4** according to the disclosure shown in FIGS. **4**A and **4**B, and do not intend to limit the communication operating bands, the applications and the specifications of the multi-antenna communication device of the disclosure in actual implementations. The multi-antenna communication device **4** according to the disclosure could be designed to cover system operating bands in WWAN (Wireless Wide Area Network), MIMO (Multi-input Multi-output) system, LTE (Long Term Evolution), pattern switchable antenna system, WLPN (Wireless Personal Network), WLAN (Wireless Local Area Network), beamforming antenna system, NFC (Near Field Communication), DTV (Digital Television Broadcasting System) or GPS (Global Positioning System). The four-antenna array **41** could be realized as a single set or multiple sets in the multi-antenna communication device **4** according to the disclosure. The multi-antenna communication device **4** could be a mobile communication device, a wireless communication device, a mobile computing device, a computer system, a telecommunication apparatus, a network apparatus or a computer or network peripheral.

FIG. **5**A is a structural diagram depicting a multi-antenna communication device **5** in accordance with an embodiment of the disclosure. FIG. **5**B is a structural diagram depicting a four-antenna array **51** of the multi-antenna communication device **5** in accordance with an embodiment of the disclosure. As shown in FIG. **5**A, the multi-antenna communication device **5** includes a grounding conductor plane **50** and a four-antenna array **51**. The grounding conductor plane **50** separates a first side space **501** and a second side space **502** opposite to the first side space **501**, and has a first edge **503**. The four-antenna array **51** is located at the first edge **503**, and has an overall maximum array length d extending along the first edge **503**. As shown in FIGS. **5**A and **5**B, the four-antenna array **51** includes a first antenna **511**, a second antenna **512**, a third antenna **513** and a fourth antenna **514**. As shown in FIG. **5**B, the first antenna **511** is located in the first side space **501**, and includes a first feeding conductor line **5112**, a first grounding conductor line **5113**, and a first radiating conductor portion **5111** electrically connected with a first signal source **5114** via the first feeding conductor line **5112** and electrically connected with the first edge **503** via the first grounding conductor line **5113**, thereby forming a first loop path **5115** and generating at least one first resonant mode. The first radiating conductor portion **5111** has a first projection line segment **5116** at the first edge **503**. The first loop path **5115** begins at the first signal source **5114**, passes through the first feeding conductor line **5112**, the first radiating conductor portion **5111**, the first grounding conductor line **5113** and the first edge **503**, and returns to the first signal source **5114**. The second antenna **512** is located in the first side space **501**, and includes a second feeding conductor line **5122**, a second grounding conductor line **5123**, and a second radiating conductor portion **5121** electrically connected with a second signal source **5124** via the second feeding conductor line **5122** and electrically connected with the first edge **503** via the second grounding conductor line **5123**, thereby forming a second loop path **5125** and generating at least one second resonant mode. The second radiating conductor portion **5121** has a second projection line segment **5126** at the first edge **503**. The second loop path **5125** begins at the second signal source **5124**, passes through the second feeding conductor line **5122**, the second radiating conductor portion **5121**, the second grounding conductor line **5123** and the first edge **503**, and returns to the second signal source **5124**. The third antenna **513** is located in the second side space **502**, and includes a third feeding conductor line **5132**, a third grounding conductor line **5133**, and a third radiating conductor portion **5131** electrically connected with a third signal source **5134** via the third feeding conductor line **5132** and electrically connected with the first edge **503** via the third grounding conductor line **5133**, thereby forming a third loop path **5135** and generating at least one third resonant mode. The third radiating conductor portion **5131** has a third projection line segment **5136** at the first edge **503**. The third loop path **5135** begins at the third signal source **5134**, passes through the third feeding conductor line **5132**, the third radiating conductor portion **5131**, the third grounding conductor line **5133** and the first edge **503**, and returns to the third signal source **5134**. The fourth antenna **514** is located in the second side space **502**, and includes a fourth feeding conductor line **5142**, a fourth grounding conductor line **5143**, and a fourth radiating conductor portion **5141** electrically connected with a fourth signal source **5144** via the fourth feeding conductor line **5142** and electrically connected with the first edge **503** via the fourth grounding conductor line **5143**, thereby forming a fourth loop path **5145** and generating at least one fourth resonant mode. The fourth radiating conductor portion **5141** has a fourth projection line segment **5146** at the first edge **503**. The fourth loop path **5145** begins at the fourth signal source **5144**, passes through the fourth feeding conductor line **5142**, the fourth radiating conductor portion **5141**, the fourth grounding conductor line **5143** and the first edge **503**, and returns to the fourth signal source **5144**. The first projection line segment **5116** and the third projection line segment **5136** are partially but not completely overlapped. The second projection line segment **5126** and the fourth projection line segment **5146** are partially but not completely overlapped. The first, second, third, and fourth resonant modes cover at least one identical first communication band, and the overall maximum array length d of the four-antenna array **51** along the first edge **503** is between 0.25 wavelength and 0.49 wavelength of the lowest operating frequency of the first communication band. The lengths of the first loop path **5115**, the second loop path **5125**, the third loop path **5135** and the fourth loop path **5145** are all between 0.1 wavelength and 0.369 wavelength of the lowest operating frequency of the first communication band. The first feeding conductor line **5112** and the first grounding conductor line **5113** are electrically connected to the first radiating conductor portion **5111**. The second feeding conductor line **5122** is spaced from the second radiating conductor portion **5121** at a second coupling gap **5127** that has an interval d**2** less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band. The second grounding conductor line **5123** is electrically connected to the second radiating conductor portion **5121**. With the second coupling gap **5127**, a capacitive reactance could be created that effectively compensates the inductance of the second loop path **5125**, thereby successfully reducing the length of the second loop path **5125**. The third feeding conductor line **5132** is spaced from the third radiating conductor portion **5131** at a third coupling gap **5137** that has an interval d**3** less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band. The third grounding conductor line **5133** is electrically connected to the third radiating conductor portion **5131**. With the third coupling gap **5137**, a capacitive reactance could be created that effectively compensates the inductance of the third loop path **5135**, thereby successfully reducing the length of the third loop path **5135**. The fourth feeding conductor line **5142** and the fourth grounding conductor line **5143** are electrically connected to the fourth radiating conductor portion **5141**. The lengths of the first radiating conductor portion **5111**, the second radiating conductor portion **5121**, the third radiating conductor portion **5131** and the fourth radiating conductor portion **5141** are all between 0.05 wavelength and 0.233 wavelength of the lowest operating frequency of the first communication band. The lengths of the first projection line segment **5116**, the second projection line segment **5126**, the third projection line segment **5136** and the fourth projection line segment **5146** are all between 0.01 wavelength and 0.22 wavelength of the lowest operating frequency of the first communication band. Each of the first signal source **5114**, the second signal source **5124**, the third signal source **5134** and the fourth signal source **5144** could be a radio frequency circuit module, a radio frequency integrated circuit die, a radio frequency circuit switch, a radio frequency filter circuit, a radio frequency duplexer circuit, a radio frequency transmission line circuit, or a radio frequency capacitance, inductance or resistance matching circuit.

In the four-antenna array **51** of the multi-antenna communication device **5**, although the first feeding conductor line **5112** is electrically connected with the first radiating conductor portion **5111**, and the fourth feeding conductor line **5142** is electrically connected with the fourth radiating conductor portion **5141**, which are slightly different from multi-antenna communication device **1**, when the first signal source **5114** and the fourth signal source **5144** are radio frequency capacitance matching circuits, capacitive reactance can also be generated, which effectively compensate the inductances of the first loop path **5115** and the fourth loop path **5145**, thereby successfully reducing the lengths of the first loop path **5115** and the fourth loop path **5145**. Therefore, by providing four adjacent and downsized first loop path **5115**, second loop path **5125**, third loop path **5135** and fourth loop path **5145** at the first edge **503**, the multi-antenna communication device **5** can effectively excite the grounding conductor plane **50** to create a more uniform strong current distribution, thus respectively producing the first resonant mode, the second resonant mode, the third resonant mode and the fourth resonant mode. This also effectively reduces the variation of input impedance of the four-antenna array **51** with frequencies, and increases the respective operating bandwidths of the first resonant mode, the second resonant mode, the third resonant mode and the fourth resonant mode. Moreover, as the four-antenna array **51** is configured with the first loop path **5115** and the second loop path **5125** at the first side space **501**, and the third loop path **5135** and the fourth loop path **5145** in the second side space **502**, the first loop path **5115** and the second loop path **5125** in the first side space **501** are able to effectively excite opposite current distributions along the first edge **503**, and the third loop path **5135** and the fourth loop path **5145** in the second side space **502** are also able to effectively excite opposite current distributions along the first edge **503**. As such, the envelope correlation coefficient between two adjacent downsized loop paths at the same side space could be effectively reduced, and the distance between the two adjacent downsized loop paths could be effectively reduced, resulting in a reduction in the maximum array length d of the four-antenna array **51** along the first edge **503**. Furthermore, by allowing the first projection line segment **5116** and the third projection line segment **5136** to be partially but not completely overlapped, and the second projection line segment **5126** and the fourth projection line segment **5146** to be partially but not completely overlapped, the space wave energy coupling between adjacent downsized loop paths in the first side space **501** and the second side space **502** could be effectively reduced, resulting in a further reduction in the overall size of the four-antenna array **51** and an improvement in the antenna radiation characteristic. Thus, the multi-antenna communication device **5** can achieve similar technical performance provided by the multi-antenna communication device **1**.

The multi-antenna communication device **5** according to the disclosure may be designed to cover system operating bands in WWAN (Wireless Wide Area Network), MIMO (Multi-input Multi-output) system, LTE (Long Term Evolution), pattern switchable antenna system, WLPN (Wireless Personal Network), WLAN (Wireless Local Area Network), beamforming antenna system, NFC (Near Field Communication), DTV (Digital Television Broadcasting System) or GPS (Global Positioning System). The four-antenna array **51** could be realized as a single set or multiple sets in the multi-antenna communication device **5** according to the disclosure. The multi-antenna communication device **5** could be a mobile communication device, a wireless communication device, a mobile computing device, a computer system, a telecommunication apparatus, a network apparatus or a computer or network peripheral.

FIG. **6**A is a structural diagram depicting a multi-antenna communication device **6** in accordance with an embodiment of the disclosure. FIG. **6**B is a structural diagram depicting a four-antenna array **61** of the multi-antenna communication device **6** in accordance with an embodiment of the disclosure. As shown in FIG. **6**A, the multi-antenna communication device **6** includes a grounding conductor plane **60** and a four-antenna array **61**. The grounding conductor plane **60** separates a first side space **601** and a second side space **602** opposite to the first side space **601**, and has a first edge **603**. The four-antenna array **61** is located at the first edge **603**, and has an overall maximum array length d extending along the first edge **603**. As shown in FIGS. **6**A and **6**B, the four-antenna array **61** includes a first antenna **611**, a second antenna **612**, a third antenna **613** and a fourth antenna **614**. As shown in FIG. **6**B, the first antenna **611** is located in the first side space **601**, and includes a first feeding conductor line **6112**, a first grounding conductor line **6113**, and a first radiating conductor portion **6111** electrically connected with a first signal source **6114** via the first feeding conductor line **6112** and electrically connected with the first edge **603** via the first grounding conductor line **6113**, thereby forming a first loop path **6115** and generating at least one first resonant mode. The first radiating conductor portion **6111** has a first projection line segment **6116** at the first edge **603**. The first loop path **6115** begins at the first signal source **6114**, passes through the first feeding conductor line **6112**, the first radiating conductor portion **6111**, the first grounding conductor line **6113** and the first edge **603**, and returns to the first signal source **6114**. The second antenna **612** is located in the first side space **601**, and includes a second feeding conductor line **6122**, a second grounding conductor line **6123**, and a second radiating conductor portion **6121** electrically connected with a second signal source **6124** via the second feeding conductor line **6122** and electrically connected with the first edge **603** via the second grounding conductor line **6123**, thereby forming a second loop path **6125** and generating at least one second resonant mode. The second radiating conductor portion **6121** has a second projection line segment **6126** at the first edge **603**. The second loop path **6125** begins at the second signal source **6124**, passes through the second feeding conductor line **6122**, the second radiating conductor portion **6121**, the second grounding conductor line **6123** and the first edge **603**, and returns to the second signal source **6124**. The third antenna **613** is located in the second side space **602**, and includes a third feeding conductor line **6132**, a third grounding conductor line **6133**, and a third radiating conductor portion **6131** electrically connected with a third signal source **6134** via the third feeding conductor line **6132** and electrically connected with the first edge **603** via the third grounding conductor line **6133**, thereby forming a third loop path **6135** and generating at least one third resonant mode. The third radiating conductor portion **6131** has a third projection line segment **6136** at the first edge **603**. The third loop path **6135** begins at the third signal source **6134**, passes through the third feeding conductor line **6132**, the third radiating conductor portion **6131**, the third grounding conductor line **6133** and the first edge **603**, and returns to the third signal source **6134**. The fourth antenna **614** is located in the second side space **602**, and includes a fourth feeding conductor line **6142**, a fourth grounding conductor line **6143**, and a fourth radiating conductor portion **6141** electrically connected with a fourth signal source **6144** via the fourth feeding conductor line **6142** and electrically connected with the first edge **603** via the fourth grounding conductor line **6143**, thereby forming a fourth loop path **6145** and generating at least one fourth resonant mode. The fourth radiating conductor portion **6141** has a fourth projection line segment **6146** at the first edge **603**. The fourth loop path **6145** begins at the fourth signal source **6144**, passes through the fourth feeding conductor line **6142**, the fourth radiating conductor portion **6141**, the fourth grounding conductor line **6143** and the first edge **603**, and returns to the fourth signal source **6144**. The first projection line segment **6116** and the third projection line segment **6136** are partially but not completely overlapped. The second projection line segment **6126** and the fourth projection line segment **6146** are partially but not completely overlapped. The first, second, third, and fourth resonant modes cover at least one identical first communication band, and the overall maximum array length d of the four-antenna array **61** along the first edge **603** is between 0.25 wavelength and 0.49 wavelength of the lowest operating frequency of the first communication band. The lengths of the first loop path **6115**, the second loop path **6125**, the third loop path **6135** and the fourth loop path **6145** are all between 0.1 wavelength and 0.369 wavelength of the lowest operating frequency of the first communication band. The first grounding conductor line **6113** is spaced from the first radiating conductor portion **6111** at a first coupling gap **6117** that has an interval d**1** less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band. The first feeding conductor line **6112** is electrically connected to the first radiating conductor portion **6111**. With the first coupling gap **6117**, a capacitive reactance could be created that effectively compensates the inductance of the first loop path **6115**, thereby successfully reducing the length of the first loop path **6115**. The second feeding conductor line **6122** is spaced from the second radiating conductor portion **6121** at a second coupling gap **6127** that has an interval d**2** less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band. The second grounding conductor line **6123** is electrically connected to the second radiating conductor portion **6121**. With the second coupling gap **6127**, a capacitive reactance could be created that effectively compensates the inductance of the second loop path **6125**, thereby successfully reducing the length of the second loop path **6125**. The third feeding conductor line **6132** is spaced from the third radiating conductor portion **6131** at a third coupling gap **6137** that has an interval d**3** less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band. The third grounding conductor line **6133** is electrically connected to the third radiating conductor portion **6131**. With the third coupling gap **6137**, a capacitive reactance could be created that effectively compensates the inductance of the third loop path **6135**, thereby successfully reducing the length of the third loop path **6135**. The fourth grounding conductor line **6143** is spaced from the fourth radiating conductor portion **6141** at a fourth coupling gap **6147** that has an interval d**4** less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band. The fourth feeding conductor line **6142** is electrically connected to the fourth radiating conductor portion **6141**. With the fourth coupling gap **6147**, a capacitive reactance could be created that effectively compensates the inductance of the fourth loop path **6145**, thereby successfully reducing the length of the fourth loop path **6145**. The lengths of the first radiating conductor portion **6111**, the second radiating conductor portion **6121**, the third radiating conductor portion **6131** and the fourth radiating conductor portion **6141** are all between 0.05 wavelength and 0.233 wavelength of the lowest operating frequency of the first communication band. The lengths of the first projection line segment **6116**, the second projection line segment **6126**, the third projection line segment **6136** and the fourth projection line segment **6146** are all between 0.01 wavelength and 0.22 wavelength of the lowest operating frequency of the first communication band. Each of the first signal source **6114**, the second signal source **6124**, the third signal source **6134** and the fourth signal source **6144** could be a radio frequency circuit module, a radio frequency integrated circuit die, a radio frequency circuit switch, a radio frequency filter circuit, a radio frequency duplexer circuit, a radio frequency transmission line circuit, or a radio frequency capacitance, inductance or resistance matching circuit.

In the four-antenna array **61** of the multi-antenna communication device **6**, although the first feeding conductor line **6112** is electrically connected with the first radiating conductor portion **6111**, and the fourth feeding conductor line **6142** is electrically connected with the fourth radiating conductor portion **6141**, which are slightly different from multi-antenna communication device **1**, the first coupling gap **6117** and the fourth coupling gap **6147** can similarly generate capacitive reactance, which effectively compensate the inductances of the first loop path **6115** and the fourth loop path **6145**, thereby successfully reducing the lengths of the first loop path **6115** and the fourth loop path **6145**. Therefore, by providing four adjacent and downsized first loop path **6115**, second loop path **6125**, third loop path **6135** and fourth loop path **6145** at the first edge **603**, the multi-antenna communication device **6** can effectively excite the grounding conductor plane **60** to create a more uniform strong current distribution, thus respectively producing the first resonant mode, the second resonant mode, the third resonant mode and the fourth resonant mode. This also effectively reduces the variation of input impedance of the four-antenna array **61** with frequencies, and increases the respective operating bandwidths of the first resonant mode, the second resonant mode, the third resonant mode and the fourth resonant mode. Moreover, as the four-antenna array **61** is configured with the first loop path **6115** and the second loop path **6125** in the first side space **601**, and the third loop path **6135** and the fourth loop path **6145** at the second side space **602**, the first loop path **6115** and the second loop path **6125** in the first side space **601** are able to effectively excite opposite current distributions along the first edge **603**, and the third loop path **6135** and the fourth loop path **6145** in the second side space **602** are also able to effectively excite opposite current distributions along the first edge **603**. As such, the envelope correlation coefficient between two adjacent downsized loop paths in the same side space may be effectively reduced, and the distance between the two adjacent downsized loop paths may be effectively reduced, resulting in a reduction in the maximum array length d of the four-antenna array **61** along the first edge **603**. Furthermore, by allowing the first projection line segment **6116** and the third projection line segment **6136** to be partially but not completely overlapped, and the second projection line segment **6126** and the fourth projection line segment **6146** to be partially but not completely overlapped, the space wave energy coupling between adjacent downsized loop paths in the first side space **601** and the second side space **602** could be effectively reduced, resulting in a further reduction in the overall size of the four-antenna array **61** and an improvement in the antenna radiation characteristic. Thus, the multi-antenna communication device **6** can achieve similar technical effect provided by the multi-antenna communication device **1**.

The multi-antenna communication device **6** according to the disclosure may be designed to cover system operating bands in WWAN (Wireless Wide Area Network), MIMO (Multi-input Multi-output) system, LTE (Long Term Evolution), pattern switchable antenna system, WLPN (Wireless Personal Network), WLAN (Wireless Local Area Network), beamforming antenna system, NFC (Near Field Communication), DTV (Digital Television Broadcasting System) or GPS (Global Positioning System). The four-antenna array **61** could be realized as a single set or multiple sets in the multi-antenna communication device **6** according to the disclosure. The multi-antenna communication device **6** could be a mobile communication device, a wireless communication device, a mobile computing device, a computer system, a telecommunication apparatus, a network apparatus or a computer or network peripheral.

The disclosure provides an integrated multi-antenna communication device with low correlation coefficient, which effectively reduces the overall size of the four-antenna array applied in the communication device and satisfies the need for high speed data transmission in future multi-antenna communication devices.

The above embodiments are only used to illustrate the principles of the disclosure, and should not be construed as to limit the disclosure in any way. The above embodiments may be modified by those with ordinary skill in the art without departing from the scope of the disclosure as defined in the following appended claims.

What is claimed is:

1. A multi-antenna communication device, comprising:

a grounding conductor plane separating along a normal direction thereof a first side space and a second side space opposite to the first side space and including a first edge; and

a four-antenna array located at the first edge and having an overall maximum array length extending along the first edge, the four-antenna array including:

a first antenna located in the first side space including a first feeding conductor line, a first grounding conductor line, and a first radiating conductor portion electrically connected with a first signal source via the first feeding conductor line and electrically connected with the first edge via the first grounding conductor line, forming a first loop path and generating at least one first resonant mode, the first radiating conductor portion having a first projection line segment at the first edge;

a second antenna located in the first side space including a second feeding conductor line, a second grounding conductor line, and a second radiating conductor portion electrically connected with a second signal source via the second feeding conductor line and electrically connected with the first edge via the second grounding conductor line, forming a second loop path and generating at least one second resonant mode, the second radiating conductor portion having a second projection line segment at the first edge;

a third antenna located in the second side space including a third feeding conductor line, a third grounding conductor line, and a third radiating conductor portion electrically connected with a third signal source via the third feeding conductor line and electrically connected with the first edge via the third grounding conductor line, forming a third loop path and generating at least one third resonant mode, the third radiating conductor portion having a third projection line segment at the first edge; and

a fourth antenna located in the second side space including a fourth feeding conductor line, a fourth grounding conductor line, and a fourth radiating conductor portion electrically connected with a fourth signal source via the fourth feeding conductor line and electrically connected with the first edge via the fourth grounding conductor line, forming a fourth loop path and generating at least one fourth resonant mode, the fourth radiating conductor portion having a fourth projection line segment on the first edge,

wherein the first projection line segment and the third projection line segment are partially overlapped, the second projection line segment and the fourth projection line segment are partially overlapped, the first, second, third, and fourth resonant modes cover at least one identical first communication band, and the overall maximum array length of the four-antenna array along the first edge is between 0.25 wavelength and 0.49 wavelength of a lowest operating frequency of the first communication band.

2. The multi-antenna communication device of claim **1**, wherein lengths of the first loop path, the second loop path, the third loop path and the fourth loop path are all between 0.1 wavelength and 0.369 wavelength of the lowest operating frequency of the first communication band.

3. The multi-antenna communication device of claim **2**, wherein the first loop path begins at the first signal source, passes through the first feeding conductor line, the first radiating conductor portion, the first grounding conductor line and the first edge, and returns to the first signal source.

4. The multi-antenna communication device of claim **2**, wherein the second loop path begins at the second signal source, passes through the second feeding conductor line, the second radiating conductor portion, the second grounding conductor line and the first edge, and returns to the second signal source.

5. The multi-antenna communication device of claim **2**, wherein the third loop path begins at the third signal source, passes through the third feeding conductor line, the third radiating conductor portion, the third grounding conductor line and the first edge, and returns to the third signal source.

6. The multi-antenna communication device of claim **2**, wherein the fourth loop path begins at the fourth signal source, passes through the fourth feeding conductor line, the fourth radiating conductor portion, the fourth grounding conductor line and the first edge, and returns to the fourth signal source.

7. The multi-antenna communication device of claim **1**, wherein the first projection line segment and the third projection line segment are partially but not completely overlapped, and the second projection line segment and the fourth projection line segment are partially but not completely overlapped.

8. The multi-antenna communication device of claim **1**, wherein the first feeding conductor line or the first grounding conductor line is spaced from the first radiating conductor portion at a first coupling gap that has a first interval less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band.

9. The multi-antenna communication device of claim **1**, wherein the second feeding conductor line or the second grounding conductor line is spaced from the second radiating conductor portion at a second coupling gap that has a second interval less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band.

10. The multi-antenna communication device of claim **1**, wherein the third feeding conductor line or the third grounding conductor line is spaced from the third radiating conductor portion at a third coupling gap that has a third interval less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band.

11. The multi-antenna communication device of claim **1**, wherein the fourth feeding conductor line or the fourth grounding conductor line is spaced from the fourth radiating conductor portion at a fourth coupling gap that has a fourth interval less than or equal to 0.023 wavelength of the lowest operating frequency of the first communication band.

12. The multi-antenna communication device of claim **1**, wherein the first feeding conductor line and the first grounding conductor line are electrically connected with the first radiating conductor portion.

13. The multi-antenna communication device of claim **1**, wherein the second feeding conductor line and the second grounding conductor line are electrically connected with the second radiating conductor portion.

14. The multi-antenna communication device of claim **1**, wherein the third feeding conductor line and the third grounding conductor line are electrically connected with the third radiating conductor portion.

15. The multi-antenna communication device of claim **1**, wherein the fourth feeding conductor line and the fourth grounding conductor line are electrically connected with the fourth radiating conductor portion.

16. The multi-antenna communication device of claim **1**, wherein lengths of the first radiating conductor portion, the second radiating conductor portion, the third radiating conductor portion and the fourth radiating conductor portion are all between 0.05 wavelength and 0.233 wavelength of the lowest operating frequency of the first communication band.

17. The multi-antenna communication device of claim **1**, wherein lengths of the first projection line segment, the second projection line segment, the third projection line segment and the fourth projection line segment are all between 0.01 wavelength and 0.22 wavelength of the lowest operating frequency of the first communication band.

18. The multi-antenna communication device of claim **1**, wherein the four-antenna array is realized as a single set or multiple sets in the multi-antenna communication device, and the multi-antenna communication device is a mobile communication device, a wireless communication device, a mobile computing device, a computer system, a telecommunication apparatus, a network apparatus or a computer or network peripheral.

19. The multi-antenna communication device of claim **1**, wherein each of the first signal source, the second signal source, the third signal source and the fourth signal source is a radio frequency circuit module, a radio frequency integrated circuit die, a radio frequency circuit switch, a radio frequency filter circuit, a radio frequency duplexer circuit, a radio frequency transmission line circuit, or a radio frequency capacitance, inductance or resistance matching circuit.

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